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volume 5 of 5 volumes

Proceedings of the
FORT UNION COAL FIELD SYMPOSIUM

Volume 5

TERRESTRIAL ECOSYSTEMS SECTION

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vol. 5 of 5 volumes

VOLUME 5

- papers of the TERRESTRIAL ECOSYSTEMS SECTION

See Volume 1 for
- Table of contents for all 5 volumes.
- Reader's guide to abbreviations.
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- Acknowledgements.

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Eastern Montana College
Billings, Montana

BIOLOGICAL EFFECTS OF COAL-FIRED POWER PLANTS

C. C. Gordon and Phillip C. Tourangeau*

The total or even partial impact of coal-fired power plant emissions upon any ecosystem in the world has never been either evaluated or quantified up to this time. While numerous personnel in Federal and state agencies, utility companies, and universities in this region are working to evaluate and quantify such potential impact on the ecosystems of the Fort Union Basin, we will not have the answers to the majority of the questions being asked and the problems to be studied for many years. In the next twenty minutes we will present portions of biological and physical studies in various areas of the U.S. where coal-fired power plants are currently operating. We will then relate this to what may be some of the more serious biological consequences of the operation of large coal-fired power plants in the Fort Union Basin.

The gases such as SO_2, NO_2, and HF emitted from coal-fired plants, singly or in concert with each other, are able to cause both short- and long- term damage to ecosystems. This damage can occur (1) by destroying all or portions of the annual or perennial foliage of plant species, (2) reducing the biomass and species diversity of the vegetation in the impact area, and (3) causing damage to the reproductive portions of plants such as pollen. These three gases also undergo chemical reactions in the atmosphere forming acids which cause the precipitation to become more acidic than normally would occur in unpolluted areas.

The particulate emissions from coal-fired power plants contain numerous trace elements such as selenium, arsenic, mercury, cadmium which singly or acting together can change or damage the physical properties and biological systems of the area they impact. Unfortunately, there is very little information available on either the short or long-term impact effects of these trace metals on ecosystems around coal-fired power plants.

We will present information gathered by various investigators on short and long-term biological effects of gaseous emissions from coal-fired power plants and on acid rains which currently are widespread throughout the industrialized Eastern U.S. There are basically two types of plant damage which can be caused by the emissions of coal-fired power plants. These are acute and chronic damage. The acute type occurs from either one or several episodes of fumigation to plant species during a short duration of time (one day to one month). The ambient air level of these phytotoxic gases of SO_2, NO_x, and HF during the acute fumigation period is usually believed to be above the air quality standards set by the Federal government and state agencies.

Chronic biological damage is that which occurs over long periods of time (several months to several years). The repeated low level fumigation and particulate fallout will cause a slow, insidious change in the metabolic and physical functions and characteristics of various animal and plant species, and changes in the soils and water of the ecosystem. Chronic damage can occur when the ambient air levels of SO_2, NO_x, and HF are below levels set by Federal or state agencies for air quality standards.

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Acute type damage around coal-fired power plants is often startling, as depicted in spectacular photographs. In July of 1972, 30 to 35 mile per hour winds of Hurricane Agnes reached the Mount Storm area of West Virginia, took the plume from the 350 foot stacks of a 1060 megawatt coal-fired power plant, and pushed it along at ground level for over 15 miles, fumigating the exposed vegetation. Another episode of acute foliar damage, where many photographs have been taken, is from an area in the western portion of West Virginia where, during an inversion breakup in 1973 near the 1000 megawatt Kyger Creek coal-fired power plant, over 2 million 2- to 3-year old conifer seedlings growing at the Clements State Tree Nursery were damaged by high level SO_2 fumigation (5).

Our last example is from the area around the 1750 megawatt TVA Shawnee steam plant located in the southwest portion of Kentucky. That is a soybean agricultural area. In July of 1971 and again twice during the summer of 1974 the plume of the Shawnee power plant fumigated at acute levels causing effects to approximately 26,400 acres of soybeans in 1971 and 41,800 acres of vegetation in 1974 (17, 15). The acute damage which occurred to the foliage of soybeans and other species was easily observeable.

After the 1971 fumigation around the Shawnee plant, TVA biologists, soil scientists, and University of Kentucky scientists studied the amount of crop loss caused by the leaf-damaging fumigation episode. The TVA conclusions from this 1971 study are only three sentences long and worth quoting here so that the audience understands better the importance of baseline data gathering prior to coal-fired power plants going on line:

> "The foliar SO_2 injury that occurred on soybean plants in the vicinity of the Shawnee steam plant in 1971 had no significant effect on soybean production. Production was being limited by low soil fertility and pH, soybean cyst nematode infestation, and possibly also other variables that were not considered in this investigation. Maximum yields should not be expected in the future unless steps are taken to correct low fertility and pH of the soil and soybean cyst nematode infestation." (17)

Physical and biological factors which had not been quantified prior to the power plant going on line were considered by the TVA investigating team to be the major causal agents of the loss of crop yield after the power plant went on line and damaged approximately 26,400 acres of soybeans. After the 1974 acute fumigation damage to 41,800 acres of vegetation in the vicinity of the Shawnee plant, TVA biologists again concluded that no reduction or economic loss to the crops had occurred, and TVA continued to uphold its no-payment-for-damage policy (15).

Acute damage to plant species from high level fumigation is usually very spectacular, and plant pathologists and air pollution specialists usually have little difficulty proclaiming which gas caused the damage and the geographical extent of the damage. On the other hand, chronic damage from the emissions of coal-fired power plants and other large stationary sources of phytotoxic gases, because of its slow and insidious nature, is much more difficult to detect and quantify. Furthermore, chronic damage, because it can occur slowly over several years and decades, is something that people (including trained air pollution specialists) can let go unnoticed and adapt to without even realizing that the ecosystem has been impacted and drastically changed.

During the 1960's and early 1970's the EPA and its precursor, the National Air Pollution Control Administration (NAPCA), carried out pollution abatement studies in various areas of the U.S., including here in Montana at Garrison, East Helena, and Glacier Park.

One of these abatement studies occurred in Kansas City, Kansas, and Kansas City, Missouri, in 1966-67 (3). Another EPA study in 1971, which was their last, was in the areas of Mount Storm, West Virginia, and Oakland, Maryland (4). We are going to use these two studies to demonstrate chronic damage to vegetation because the major air pollution sources in both of the above areas were coal-fired power plants. Also in both study areas EPA conducted air quality measurements together with quantified plant damage studies. These allow us to demonstrate that chronic air pollution damage to vegetation can occur when air pollutant levels are below Federal and state air quality standards.

In the Kansas City study (3) at one of the air monitoring stations (Waterworks), various sensitive plant species were cultivated in two separate greenhouses. In one greenhouse all the incoming air was filtered to remove the phytotoxic gases in the ambient air. Unfiltered ambient air was allowed into the other greenhouse 24 hours a day. We show in Table I the plant growth suppression which occurred to the plants grown in ambient air as opposed to those in charcoal filtered air at the Waterworks study site. On Table I is the measured loss of biomass to tobacco plants grown in filtered air. In Table II we present the two-hour and daily SO_2 concentration levels at the Kansas City Waterworks study site. We can see from the data on this table that during the ten-month period (December to October) the SO_2 concentration exceeded the current three-hour Federal standard of .05 ppm for only 36 hours and that these violation periods were not during the growing season, but between December and February. More important, however, is that the average daily SO_2 levels recorded at the Waterworks study site are only half the concentrations allowed by Montana state law--which is 0.10 ppm for a 24-hour average, not to be exceeded over one per cent of the days in any three-month period. Furthermore, the maximum two-hour SO_2 concentration at the Waterworks site during the entire study was 0.14 ppm which is approximately half of the State of Montana maximum one-hour SO_2 standard of 0.25 ppm, not to be exceeded more than one hour in any four consecutive days. Thus, in Montana and Colstrip it is possible to have more SO_2 polluted air than that which occurred at the EPA Waterworks study site where plant growth was suppressed by 25 to 50 per cent compared to the plants growing in filtered, clean ambient air.

In the Mount Storm area of West Virginia there are approximately one million acres of Christmas tree plantations cultivated by growers during the last 30 years. During the period of 1965 to 1971 three coal-fired power plants, each in excess of 1000 megawatts, were built and began steam generation within a 50-mile radius of these conifer three plantations. Collectively, these three power plants (with a little support from an older 400 megawatt power plant within the 50-mile radius) release 788,000 tons of SO_2 annually into the atmosphere along with large quantities of NO_x, particulates, substantial quantities of fluorides, and an unknown amount of trace metals. During the summer of 1970 the EPA air pollution abatement team carried out extensive air monitoring, meteorological measurements and modeling, and biological studies on three of the Christmas tree farms suffering damage by air pollution. These farms were located 2, 10, and 15 miles away from the nearest coal-fired power plant (the 1060 megawatt Virginia Electric and Power Company's Mount Storm Station located at the Stoney Reservoir near Mount Storm, West Virginia). Table III shows the concentration of SO_2, NO_x, and oxidants during the 1970 growing season at these three plantations. We can see that neither the Federal standard of .05 ppm for three hours for SO_2 nor .05 ppm annually for NO_x were exceeded to any degree at the three plantation sites. The oxidant levels which include ozone (O_3) were often higher at the three plantations than allowed by the Federal standards of .08 ppm for a half hour period not to be exceeded over one time per year.

While air pollution damage to the conifers in the form of needle tip burn was present at these plantations before, during, and after 1970, the major plant damage was caused by the acid rains which impacted the trees causing the chronic type damage of overall reduced growth and vigor, premature needle casting, and stunting of the leaves or needles. In Table IV are the results of a study on the precipitation which was collected in the Mount Storm area during 1972. This table also presents the results of 1973-74 precipitation studies carried out on rainwater collected in a 30-mile radius of East Helena, and Anaconda, Montana, and in an 80-mile radius of Colstrip, Montana by the staff of the Environmental Studies Laboratory at the University of Montana. We have also included in Table IV the pH levels of rainfall collected by TVA personnel around Cumberland, Tennessee, prior to the TVA 2600 megawatt Cumberland coal-fired power plant going on line. As can be seen on this table, the average pH of rainwater samples collected in the Colstrip area during 1973-74 was 6.5 with the lowest reading of any given sample being 5.2 and the highest 8.6. In the Mount Storm area the average pH value of all the rainwater samples collected and analyzed was 4.8, which shows that on the average the acid content of the rainwater from the Mount Storm area was approximately fifty times greater than that of the Colstrip precipitation. The average pH of the rainwater from the Mount Storm area was approximately the same as that which was found to be the baseline level in the Cumberland area prior to the TVA Cumberland power plant going on line. We will come back to these baseline pH levels at Cumberland in a few minutes after we show some of the chronic type damage which occurred to the conifers in the Mount Storm area from acid rains.

In Figure 1a are two Scotch pine branches, one that was collected from a healthy tree and the other from a diseased tree in the Mount Storm area. This figure depicts the condition which became commonly known as the short-long needle syndrome which occurs when the acidic rain falls upon the young emerging needles during the candle stages in the spring and early summer of each year. The acidic precipitation penetrates beneath the fascicular sheath and burns the young tissues. The acid rain damage can be considered hidden since it occurs beneath the sheaths at the base of the needles, as depicted in Figure 1b. The next figure, number 1c, demonstrates the typical type of tissue pathology present in the needle base. This type of damage causes the needles to be cast from the trees earlier than normal and results in a reduction in growth of the trees. Probably more important to coniferous forests is what the acid rains do to the dwarf shoot buds which are the precursors of the lateral branches and the male and female cones. In Figure 1d are the damaged dwarf shoot buds of Ponderosa pine destroyed by the acid rains falling here in the Pacific Northwest close to large stationary sources of SO_2 and other phytotoxic gases.

There have not been many studies in the past on the biological impact of acidic precipitation. However, widespread concern about the ever-increasing acidity of rainfall in the U.S. and Western Europe has caused biological and physical scientists of both areas, and medical research teams of many universities and institutes, to begin an increasing number of studies on this phenomenon and its biological, physical, and human impacts.

The effects of SO_2 and NO_x on vegetation are well documented. However, scientists are just beginning to realize the deleterious effects of acidic precipitation resulting from the injection of these gaseous pollutants into the atmosphere from tall stacks.

Gordon (12, 13) found that certain foliar abnormalities of several species of conifers were caused by acid rain, and Richards (21) proposed that a hormonal imbalance was indicated. Others have demonstrated direct damage to herbaceous and coniferous species with simulated acid rain (10, 23, 16). Possibly of more importance, however, are studies which show an effect at the intracellular level, which indicate deleterious structural or physiological effects on the developmental and photosynthetic systems (12, 10, 23). Interactions with certain plant diseases including pathogenic fungi and bacteria have been shown (22).

A number of investigations in Scandinavia and the U.S. have indicated progressive decline in coniferous and hardwood forests resultant from acidic precipitation (7, 18, 21, 24). Although the Scandinavian studies suggest a leaching of soil nutrients, leaching of foliar nutrients has been observed also (9, 25, 26). Most of the above studies indicate a reduction in volume or yield, and others have reported similar results with crop species (8, 10).

In addition to the direct effect on plant organisms, the action of acid deposition by wet or dry mechanisms has been investigated. Although acid deposited in soil will be neutralized, the neutralization is the result of leaching of cations, including important nutrients (20, 7, 21). Also SO_2 absorbed by soil contributes to these processes, since it is oxidized to sulfuric acid (20).

There is the possibility, depending upon the soil, that runoff water may still be acidic (7, 19, 21) and acidification of lakes and streams has been measured in Scandinavia and North America (7, 6). Studies have been reported showing effects on fish which may result from increased acidification (14, 6). Presumably, the oceans are sufficiently well buffered so that significant acidification will not occur to them before supplies of fossil fuels are exhausted. However, estuaries, the coastal zones, and surface waters are particularly susceptible to effects of acidification, since they are important for the maintenance of many aquatic organisms at critical stages of their life cycles.

Returning to the problem of increasing soil acidity caused by acid rains and other means of deposition, we present the following quotation on the costs to rectify this in our agricultural land:

> "If it is assumed, as a rough approximation, that half the sulfur oxides emitted are deposited as acid forming substances on agricultural land, the projected emission of 19 million tons of additional SO_2 in 1980 would require the use of about 12 million tons of additional lime. At a current cost of \$14-\$18 per ton, including spreading (sic) this would involve additional costs approaching \$200 million annually." (1)

If we compare these predictions with the TVA conclusions on the impact of their 1971 Shawnee plant's fumigation of soybeans, one might feel that the farmers in the area of the TVA power plants are on the losing side of the argument. We come to this conclusion because of what we find in the graphs and tables which have been prepared from data collected during the last few months on the operations of TVA power plants.

On Figure II are the locations and the megawatt capacity of the twelve TVA power plants currently operating in the Southeast U.S. The total megawatt capacity of these twelve TVA coal-fired power plants is 17,725, and during 1973, according to Mr. John Fry of TVA (11), 37½ million tons of coal were burned at these twelve plants to generate electricity. The burning of this 37½ million tons of coal in 1973 released into the atmosphere: 2,033,437 tons of SO_2, 1½ million tons of particulate (see Table V), approximately one million tons of nitrogen oxides (Table VI), and 1000 tons of gaseous and particulate fluoride. Now if one turns back to Table IV which depicts the baseline levels of the pH of rainwater at the five stations around Cumberland, Tennessee, in 1971-72 prior to TVA's 2600 megawatt Cumberland steam plant start-up, one notes that the baseline levels of rainwater acidity were approximately 50 times more acidic there than the baseline levels found in precipitation in the Colstrip area of Montana. The baseline amount of sulfate ($SO_4^=$) and elemental sulfur impacting the area around Cumberland prior to the going-on-line of the power plant is shown in Table VII. One of these stations (TVA-C), the control, is approximately 50 miles from the 1750 megawatt TVA Shawnee power plant where, as previously discussed, the TVA investigations (17) concluded that the farmers would have to rectify the low pH and soil fertility plus eradicate the soil nematode infestation if they expected to improve their crop production. If we consider the conversion rate and residence time of SO_2 in the ambient air, then the biological impact of coal-fired power plant emissions in the TVA power plant areas was probably present soon after the first TVA power plants went on line in the 1940's. We can only conclude, based on their own results, that all baseline pre-operational data gathered by TVA since the early 1950's have been used by that agency to show that their impacted areas are normal.

In conclusion, we present three maps of the U.S. which illustrate some of the major reasons that baseline data gathering must take place prior to the development of coal-fired power plants in the Fort Union Basin and along the Rocky Mountain states. If not completed in the immediate future, the chance for these studies will never again occur anywhere inside the 48 contiguous states. Figures III and IV were prepared by Dr. Larry Neimeyer, an EPA atmospheric scientist, who presented them at an EPA abatement hearing in 1971 concerning air pollution problems in the Mount Storm area of West Virginia. In Figure IV Dr. Neimeyer has projected the siting of new steam generating plants by 1990--primarily in the Central, Eastern, and Western states. However, if we look at Dr. Carl Shy's data on SO_2 and sulfates (Figure V) presented in the EPA medical CHESS Report and in public testimony on the current SO_4 levels over the industrialized Central and Eastern U.S. (2, 24), we realize that Neimeyer's projection of future siting cannot be correct unless we either: (1) use the best and most efficient emission abatement equipment, or (2) prepare to sacrifice the health and welfare of the citizens and their environment in these Central and Eastern states. What we can expect here in the Northern Rocky Mountains and Great Plains are efforts to shift a large number of steam plants to this clean area of the U.S. As this projected shift and building of power plants occurs in the Rocky Mountains, numerous scientists will remain busy in determining the environmental impact of the emissions from these power plants. We are sure that much will be learned which is new to the scientific community on the impact of such emissions upon the land. However, there remains little doubt in our minds that enough scientific data is available now that we can predict that the forests, agricultural areas, and grazing lands will be impacted and damaged. The farmers, cattlemen , and foresters of this area will have to work much harder and spend more money in the future to produce their crops. We believe this because of what has been told to the farmers of the Mount Storm area and the Shawnee, Kentucky area in the past by the scientists who defend the emissions of coal-fired power plants.

TABLE I

GROWTH SUPPRESSION OF EXPERIMENTAL VEGETATION[a][b]

(per cent less than control)

Vegetation	Waterworks	Police Garage	Morse School	Waterworks Control
Tobacco	30	20	30	0
Pinto Bean	25	15	30	0
Petunia	40	15	40	0
Geranium	25	25	30	0
Begonia	50	15	50	0
Corn	25	15	25	0

[a] Estimated by visual comparison

COMPARISON OF EXPOSED AND CONTROL TOBACCO PLANT GROWTH[b] BETWEEN 7/17/67 - 9/5/67

	Waterworks	Police Garage	Morse School	Control
Percent of leaf area damaged	30	20	30	0
Diameter of stem, in.	0.61	0.62	0.56	0.73
Stem cross-section area, in.^{2}	0.29	0.30	0.25	0.42
Cross-section area, percent less than control	30	30	40	0
Root system weight, grams	405	428	328	576
Percent root system weight less than control	30	26	43	0

[b] Source: Kansas City, Kansas--Kansas City, Missouri, Air Pollution Abatement Activity. Phase II, Pre-Conference Investigations. HEW, PHS, Cincinnati, Ohio. 1968.

TABLE II

CUMULATIVE PER CENT FREQUENCY OF OCCURRENCE OF DAILY AVERAGE SULFUR DIOXIDE CONCENTRATION VARYING PERIODS - 1966-67[a]

Station Location	Concentration, ppm					
	% of time, stated value exceeded:					
	90-50	25	10	1	Max Value	Arith Mean
Waterwords	<.01	.01	.02	.04	.05	.01
Police Garage	<.01	.02	.03	.05	.08	.01
UMKC Campus	<.01	.01	.01	.02	.02	.01
Morse School	<.01	.01	.02	.04	.04	.01

CUMULATIVE PER CENT FREQUENCY OF OCCURRENCE OF 2-HOUR SULFUR DIOXIDE CONCENTRATION - 1966-67[a]

Station Location	Concentration, ppm					
	% of time, stated value exceeded:					
	90-30	16	10	1	Max Value	Arith Mean
Waterworks	.01	.01	.02	.09	.14	.01
Police Garage	.01	.02	.03	.10	.20	.01
UMKC Campus	.01	.01	.01	.03	.11	.01
Morse School	.01	.01	.02	.06	.15	.01

[a] Source: Kansas City, Kansas--Kansas City, Missouri, Air Pollution Abatement Activity. Phase II, Pre-Conference Investigations. HEW, PHS, Cincinnati, Ohio. 1968.

TABLE III

SUMMARY OF HOURLY SULFUR DIOXIDE MEASUREMENTS, MAY 28 THROUGH SEPTEMBER 28, 1970[a]

Station		Concentration, ppm		per cent observations equal to or exceeding	
		Maximum value	Average value	.02 ppm	.10 ppm
Stoney River	2 miles	.36	.01	10.6	1.2
Steyer #2	10 miles	.11	.01	10.3	.1
Weise McDonald	15 miles	.10	.01	9.0	.1

SUMMARY OF HOURLY NITROGEN OXIDES MEASUREMENTS MAY 28 THROUGH SEPTEMBER 27, 1970[a]

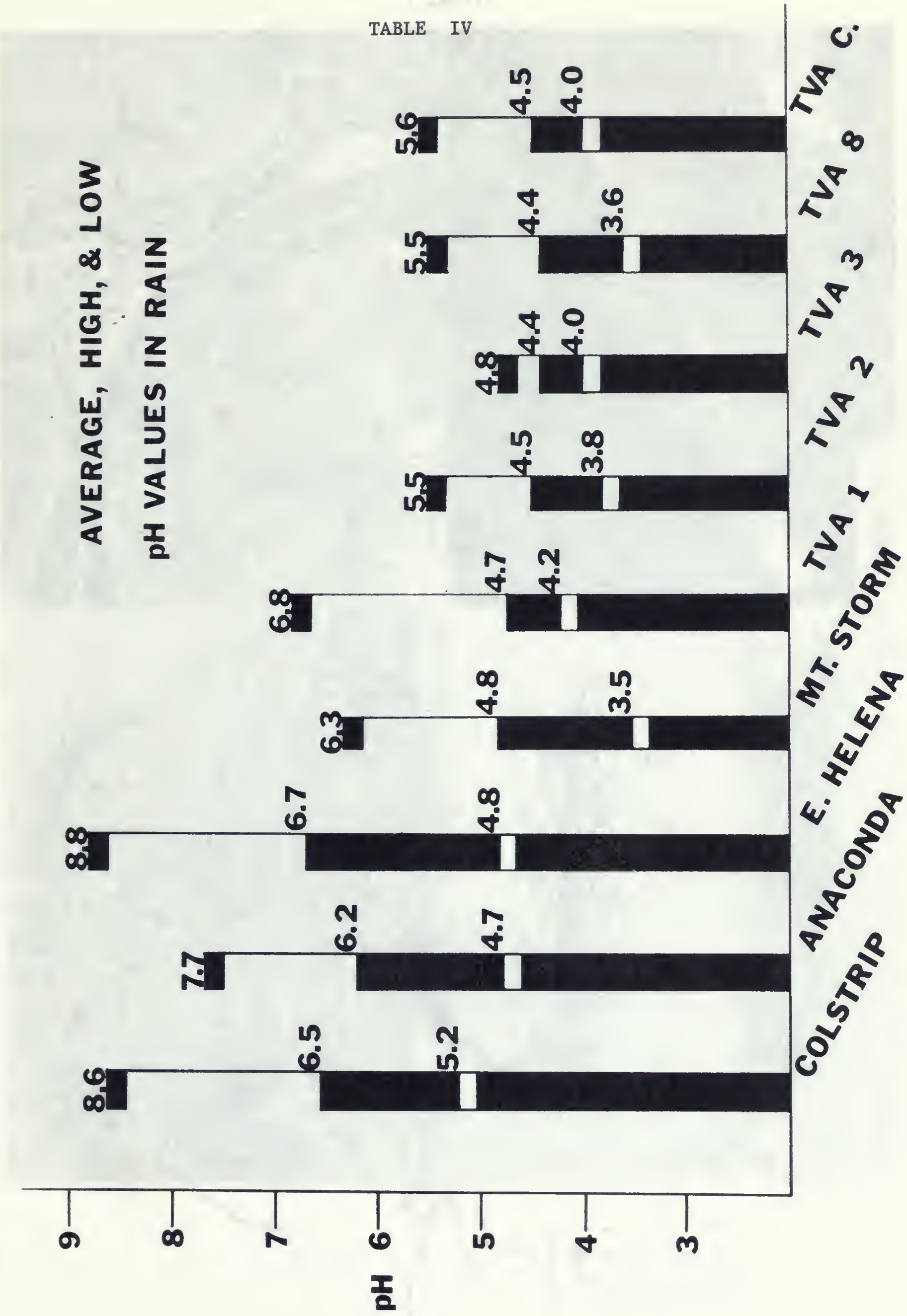
Station		Concentration, ppm		per cent observations equal to or exceeding	
		Maximum value	Average value	.02 ppm	.05 ppm
Stoney River	2 miles	.08	.01	1.9	.4
Steyer #2	10 miles	.02	.01	1.3	.0
Weise McDonald	15 miles	.03	.01	4.8	.0

SUMMARY OF HOURLY OXIDANT MEASUREMENTS, MAY 29 THROUGH SEPTEMBER 28, 1970[a]

Station		Concentration, ppm		per cent observations equal to or exceeding	
		Maximum value	Average value	.06 ppm	.01 ppm
Stoney River	2 miles	.15	.06	60.8	5.7
Steyer #2	10 miles	.13	.05	47.0	3.0
Weise McDonald	15 miles	.13	.06	46.0	3.6

[a] Mount Storm, West Virginia--Gorman, Maryland, and Luke, Maryland--Kaiser, West Virginia, Air Pollution Abatement Activity. U.S. EPA, APCO, Research Triangle Park, North Carolina. 1971. APTD-0656.

TABLE IV



AVERAGE, HIGH, & LOW pH VALUES IN RAIN

FIGURE I

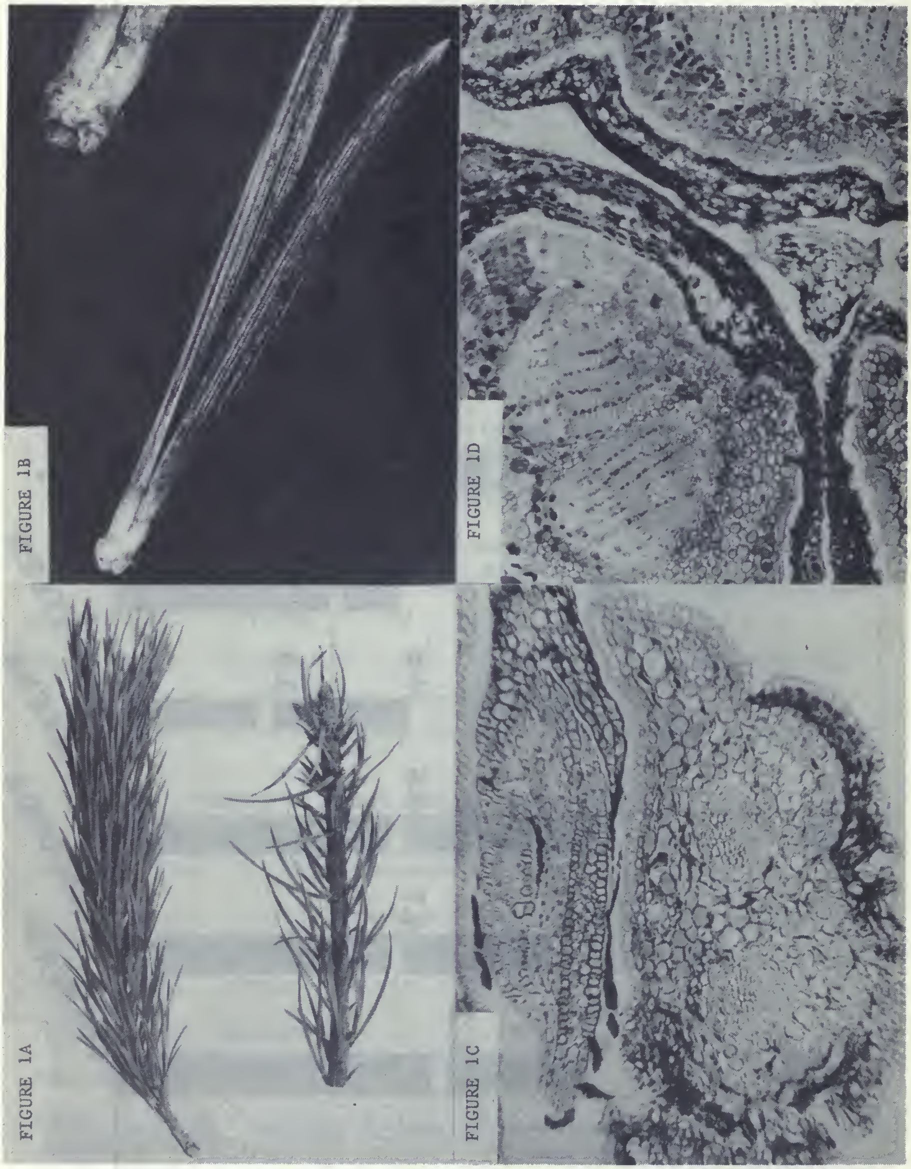
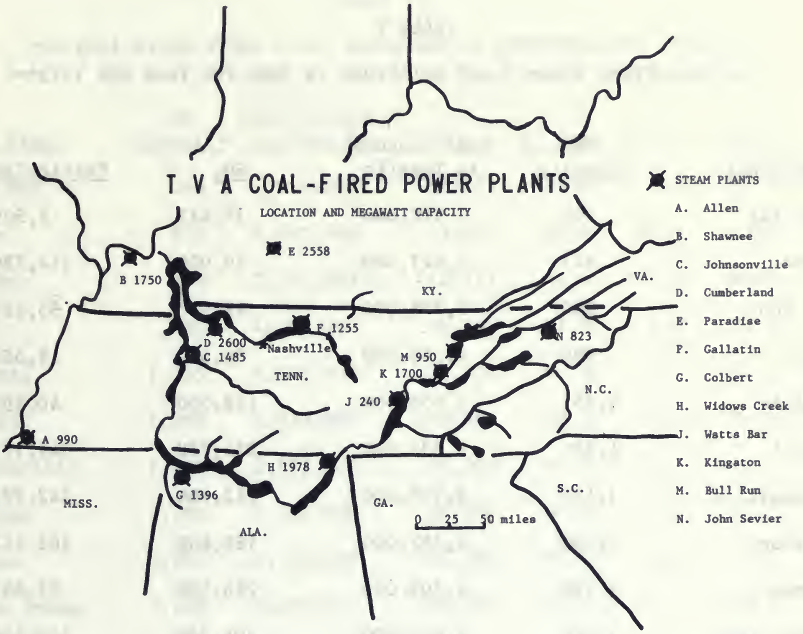


FIGURE 2


T V A COAL-FIRED POWER PLANTS
LOCATION AND MEGAWATT CAPACITY
STEAM PLANTS
A. Allen
B. Shawnee
C. Johnsonville
D. Cumberland
E. Paradise
F. Gallatin
G. Colbert
H. Widows Creek
J. Watts Bar
K. Kingston
M. Bull Run
N. John Sevier
A 990
B 1750
C 1485
D 2600
E 2558
F 1255
G 1396
H 1978
J 240
K 1700
M 950
N 823
Nashville
KY.
TENN.
VA.
N.C.
S.C.
GA.
ALA.
MISS.
0 25 50 miles

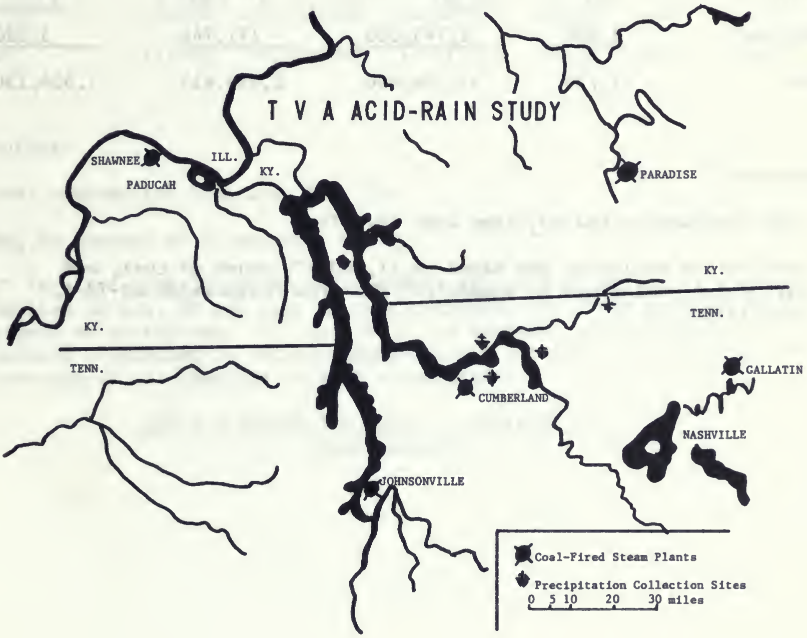

T V A ACID-RAIN STUDY
SHAWNEE
PADUCAH
ILL.
KY.
PARADISE
KY.
TENN.
KY.
TENN.
CUMBERLAND
GALLATIN
NASHVILLE
JOHNSONVILLE
Coal-Fired Steam Plants
Precipitation Collection Sites
0 5 10 20 30 miles

TABLE V

TVA COAL-FIRED STEAM PLANT EMISSIONS IN TONS PER YEAR FOR 1973***

Steam Plant	MW Capacity	Coal Consump. in Tons/Yr	SO_2	Particulate
Watts Bar	240	518,000	35,431	1,509
Sevier	823	1,822,000	59,000	114,720
Bull Run	950	2,375,000	42,750	55,123
Allen	990	1,554,000	89,510	19,658
Gallatin	1,255	3,050,000	148,200	40,595
Colbert	1,396	2,933,000	211,200	344,177
Johnsonville	1,485	3,192,000	212,600	242,272
Kingston	1,700	4,282,000	169,600	102,117
Shawnee	1,750	4,703,000	228,600	22,865
Widows Creek	1,978	3,669,000	204,700	539,438
Paradise	2,558	6,668,000	504,100	40,488
Cumberland	2,600	2,743,000	177,746	3,228
TOTALS	17,725	37,509,000	2,033,437	1,526,130

***Sources:

1. Coal consumption and SO_2 from John Fry, TVA
2. Particulate estimates are based on 11,000 BTU/pound of coal, and particulate emissions in pounds/10^6 BTU from Publication AQ-72-1, TVA, 1973.

TABLE VI

TVA COAL-FIRED STEAM PLANT EMISSIONS IN TONS/YEAR FOR 1973***

Steam Plant	MW Capacity	Coal Consump. in Tons/Yr	NO_x	F^- Gas	F^- Part.	F^- Total
Watts Bar	240	518,000	17,715	10.4	0.8	11.2
Sevier	823	1,822,000	29,506	36.4	27.4	63.8
Bull Run	950	2,375,000	21,375	47.5	13.4	60.9
Allen	990	1,554,000	44,755	31.0	6.2	37.2
Gallatin	1,255	3,050,000	74,100	61.0	4.6	65.6
Colbert	1,396	2,933,000	105,600	58.6	37.5	96.1
Johnsonville	1,485	3,192,000	106,300	63.8	34.1	97.9
Kingston	1,700	4,282,000	84,800	85.6	9.9	95.5
Shawnee	1,750	4,703,000	114,300	94.0	5.6	99.6
Widows Creek	1,978	3,669,000	102,350	73.4	36.3	109.7
Paradise	2,558	6,668,000	252,050	133.4	10.0	143.4
Cumberland	2,600	2,743,000	88,873	54.8	0.8	55.6
TOTALS	17,725	37,509,000	1,041,718	794.9	186.6	936.5

***Sources:

1. Coal consumption from John Fry, TVA.

2. NO_x is assumed to be one-half of SO_2.

3. F^- is based upon 50 ppm in coal. Of F^- charged, 40 per cent is assumed emitted as gas; 60 per cent to precipitators. No F^- is assumed to remain as bottom ash. All gaseous F^- is emitted, and particulate F^- is assumed controlled in efficiencies which are determined as weighted averages of all controls at each steam plant:

$$\frac{(\text{MW x \% control}) + (\text{MW x \% control}) + \ldots.}{\text{Plant capacity}}$$

TABLE VII

TVA COAL-FIRED STEAM PLANTS
TOTAL EMISSIONS FOR 1973 IN TONS[a]

MEGAWATT CAPACITY	17,725
COAL CONSUMPTION	37,509,000
SO_2	2,033,437
PARTICULATE	1,526,130

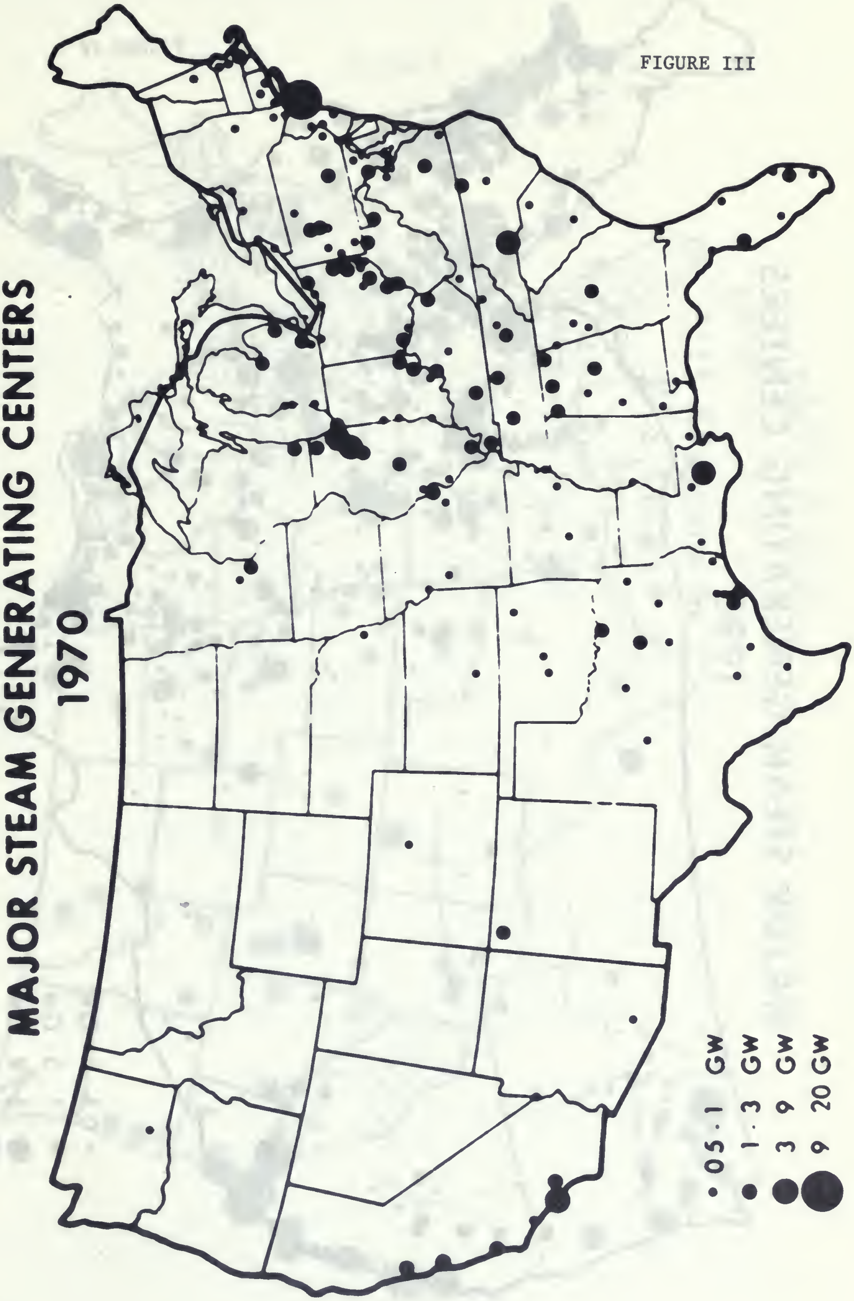
TOTAL SULFATE AND SULFUR DEPOSITED IN PRECIPITATION IN THE CUMBERLAND STEAM PLANT AREA, SEPTEMBER, 1971 - JULY, 1972[b]

STATION	TOTAL VOLUME OF PRECIPITATION	SO_4 CONTENT pounds/acre	ELEMENTAL SULFUR pounds/acre
1	32.8_L	46.6	15.5
2	32.1_L	53.6	17.9
3	29.5_L	46.3	15.4
8	22.1_L	37.2	12.4
CONTROL	25.4_L	46.6	15.5
AVERAGE	28.4_L	46.0	15.3

[a] Source: John Fry, TVA

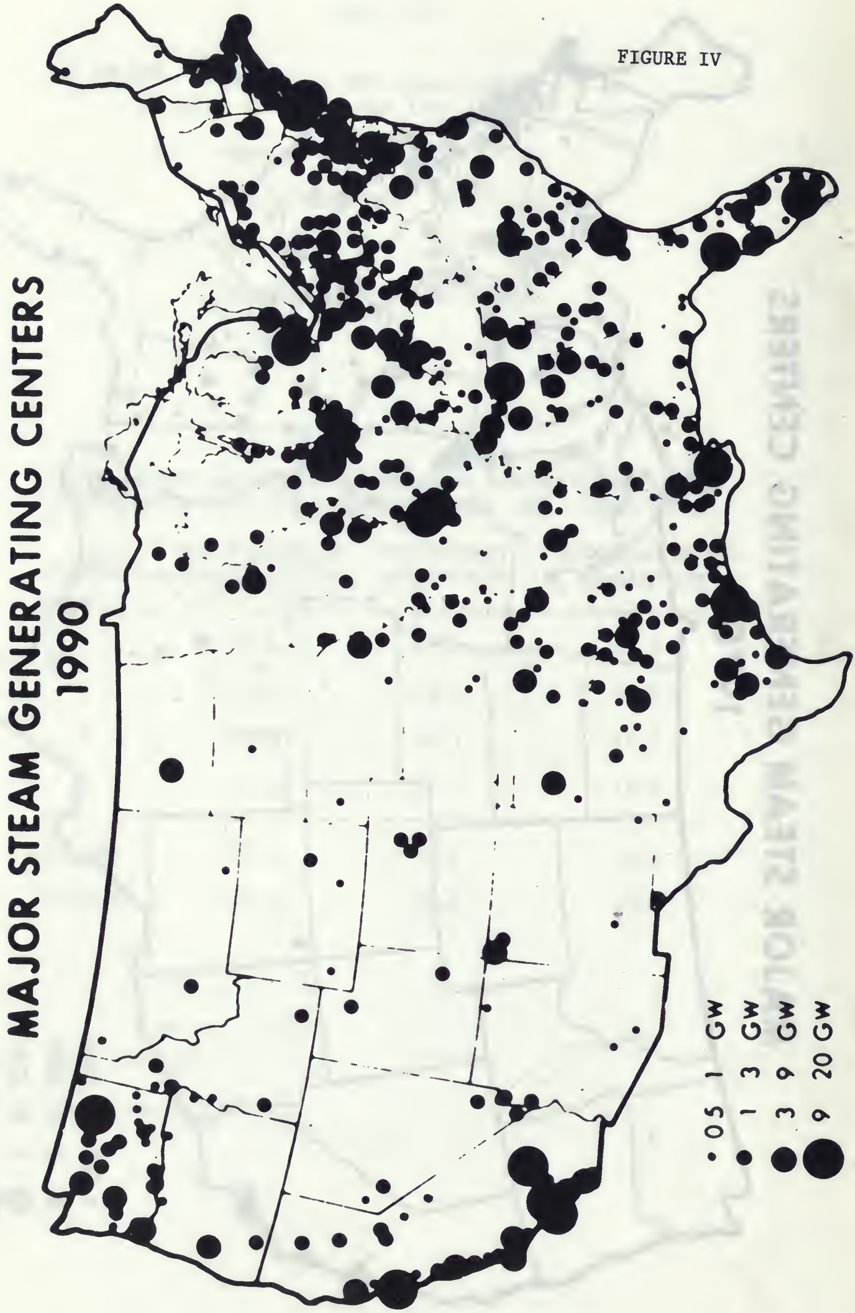
[b] Source: Herb Jones, TVA

FIGURE III



MAJOR STEAM GENERATING CENTERS
1970

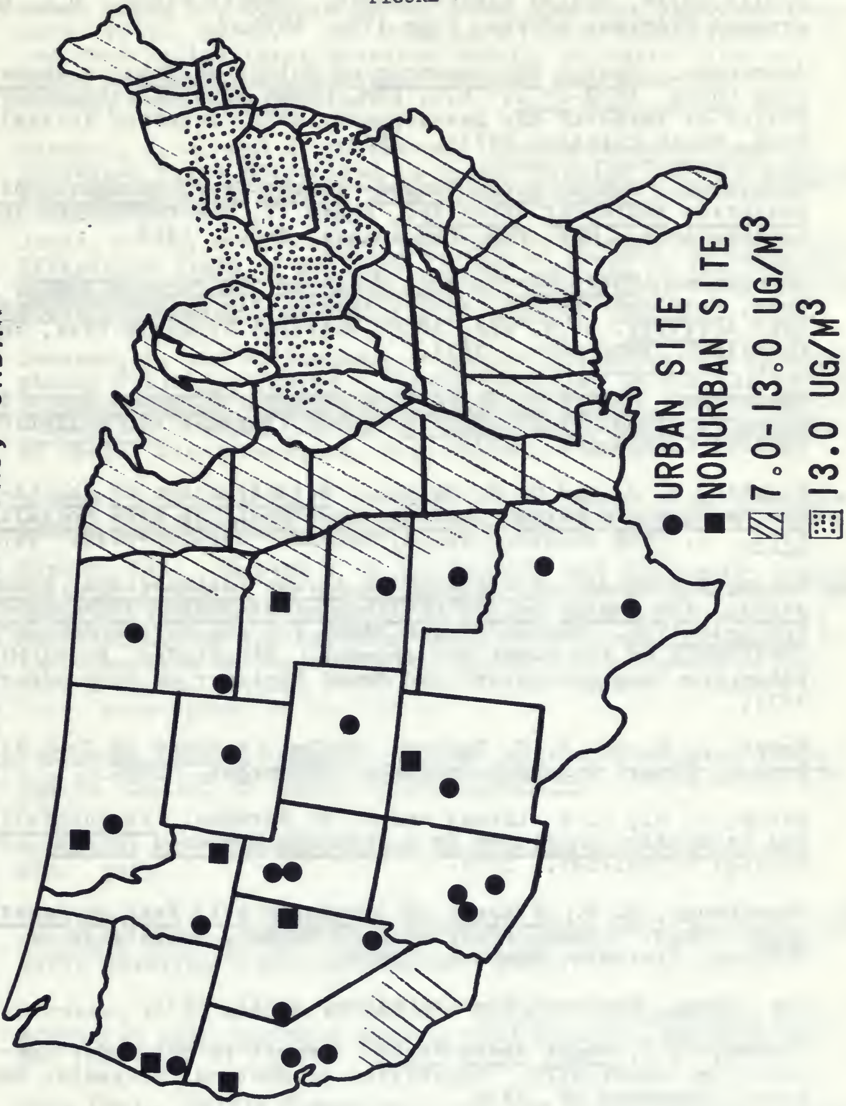
FIGURE IV



MAJOR STEAM GENERATING CENTERS
1990

FIGURE V

1970 SULFATE CONCENTRATIONS, URBAN



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Fort Union Coal Field Symposium

531

AN INVESTIGATION OF THE BIOENVIRONMENTAL EFFECTS OF A COAL-FIRED POWER PLANT

by

Robert A. Lewis, Allen S. Lefohn, and Norman R. Glass*

INTRODUCTION

The United States presently faces a series of problems concerning the production, distribution, and consumption of fossil fuel energy. Because of great abundance at relatively low cost, the Administration's commitment to energy self-sufficiency by 1980 and other factors, it is clear that the United States is moving toward an economy based on coal as the primary fossil fuel resource. The rush toward energy self-sufficiency will result in new pressures on the environment. The decisions that will ultimately resolve the environmental and economic issues we face must be made with full knowledge of the constraints imposed by the need to minimize environmental impacts associated with energy production and utilization.

Currently, over 95 percent of the primary energy in the United States is produced through the combustion of fossil fuels (the remainder is derived from hydro power and nuclear energy). By the year 2000, the fossil fuel contribution to the total energy economy is expected to be approximately 70 percent, but total usage of fossil fuels will probably increase by more than 100 percent. During the same period, nuclear energy production is expected to grow ten-fold.

There is a clear relationship between research conducted on energy related problems and research which has been carried out for the purpose of setting or revising air and water quality standards designed to maintain environmental quality. This is due to the fact that environmental research designed to determine the effects on biota and ecological processes is concerned with the same types of pollutants or residuals for standard setting purposes as for purposes of identifying the effects of energy extraction, conversion, or generation. For example, ambient air quality standards have been established under the Clean Air Act Amendments of 1970 for the major, but not all, pollutants generated by fossil fuels. National Ambient Air Quality Standards (NAAQS) have been established for sulfur oxides, particulates, carbon monoxide, nitrogen oxides, hydrocarbons, and oxidants. These standards were based upon the best information available at the time of their promulgation. New source performance standards (NSPS) have been established for several industries including electric utilities. These standards place restrictions on the emissions of SO_x, NO_x, particulates, and other pollutants. These standards apply to the operation of fossil fueled generating plants, the construction or modification of which started after August 1971.

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The Clean Air Act states that "...air quality criteria for an air pollutant shall accurately reflect the latest scientific knowledge useful in indicating the kind and extent of all identifiable effects on public health or welfare which may be expected from the presence of such pollutants in the ambient air, in varying quantities" (section 108(a)). The Act further states that national primary ambient air quality standards are regulations which "in the judgment of the administrator, based on such criteria, and allowing for an adequate margin of safety, are requisite to protect the public health" (section 109(b)). Air quality criteria, then reflect scientific knowledge, while primary air quality standards involve a judgement as to how this knowledge must be used in a regulatory action to protect public health, and the secondary air quality standards determine the level of air quality required to protect the public welfare. Public welfare as defined in the Clean Air Act "includes, but is not limited to, effects on soils, water, crops, vegetation, manmade materials, animals, wildlife, weather, visibility, and climate..." (section 302(h)). These considerations also apply and become focal points for energy related environmental research. It is clear that the research experience gained in furtherance of the Clean Air Act is valuable in pursuing energy related research - in fact, the objectives of each set of research programs is so similar that clear separation is not possible.

The major categories of air pollutants emanating from fossil fuel energy systems are sulfur oxides, nitrogen oxides and particulate matter. Energy systems also contribute, to a lesser degree, to carbon monoxide and oxidant burdens. Primary ambient air standards, based on health effects have been established for these pollutants. Secondary standards have been established for SO_2, particulates, CO, oxidants, hydrocarbons, and NO_2. These standards were based on the best scientific information available at the time of their creation. However, at the time they were set, significant gaps in knowledge existed; even now important gaps in knowledge still exist for each pollutant. Accordingly, under the Clean Air Act, EPA is required to continually examine and update the criteria upon which these standards are based. In addition to the above pollutants, numerous trace metals such as copper, cadmium, zinc, lead, arsenic, mercury, and others, are emitted from fossil fueled power generating plants. Numerous other trace contaminants in the form of hydrocarbons and various aerosols are also emitted from power plants. In general, trace metals are emitted as particles adsorbed to fly ash or other particulate matter coming from the stack of the coal-fired power plant.

The following discussion represents an overview of the National Ecological Research Laboratory's recently initiated coal-fired power plant project. The broad objective of this program is to measure and predict change in a grassland ecosystem as a function of meaningful environmental parameters including air pollutants. This study is concerned not only with the stability of ecosystem organization in relation to ambient conditions, but also with the predictability and reproducability of changes that do occur. Insight into the mechanisms of dynamic-structural responses of ecosystem components to air pollution challenge is also sought. It is particularly important to identify the subsystem functions that contribute to ecosystem regulation and mechanisms whereby such regulation is effected.

This investigation thus represents an attempt to characterize the impact of air pollutants on a total ecosystem. It is the first attempt to generate methods to predict bioenvironmental effects of air pollution before damage is sustained. Historically, most terrestrial air pollution field research has dealt almost exclusively with direct, usually acute, effects on vegetation. We expect to observe complex changes in ecosystem dynamics as a function of relatively long term, chronic pollution challenge. By studying a rather broad range of interacting variables, we hope to isolate some of these as sensitive and reliable measures of air pollution impact.

The approach envisioned requires (1) the use of reasonably comprehensive models of component populations of the ecosystems; (2) the use of appropriately structured field and laboratory experiments; and (3) an evaluation of physiological and biochemical functions that may serve as specific indicators or predictors of air pollution stress.

Even in a comprehensive investigation, extensive studies of a large array of species or processes is not possible. Considerable research is required to identify the specific parameters that will give an adequate, sensitive measure of air pollution to a grassland ecosystem or components thereof. Broad categories of important functions that we are investigating include (1) productivity or biomass of ecosystem compartments; (2) life-cycle and population dynamic functions of "key" taxa; (3) community structure or diversity; (4) nutrient cycling; (5) sublethal biochemical or physiological changes in individuals or compartments; (6) behavior of mobile organisms; and (7) reproductive patterns and breeding success of terrestrial vertebrates.

If we are to assess and interpret the effects of air quality upon natural ecosystems, it is essential that we understand the wide range of abiotic factors (e.g., weather, geography, insolation, hydrology, etc.) that influence the dynamics of the living components of the ecosystem. Optimum production, the maintenance of stability and diversity, and other desirable properties of ecosystems all depend upon a variety of these abiotic factors. Thus, appropriate micrometeorological and air quality support is provided to this study.

RATIONALE

In addition to the "simple" direct effects of air pollutants that have been reported from experimental studies of natural systems, we may expect to observe complex changes in ecosystem dynamics as a function of pollution challenge. We know that insults to the environment from rather diverse sources (toxic substances, pesticides, radiation, disease, and adverse climate) produce a similar array of effects at the community level in spite of very different effects on individual organisms studied under experimental conditions. The response mechanisms may vary, but results are often similar: (1) a "reversal" of succession or simplification of ecosystem structure; (2) a reduction in the ratio of photosynthesis to respiration; and (3) a reduction in species diversity at more than one trophic level, which may include the elimination of certain species (e.g., in grassland, usually rare, but characteristic species). Effects may be temporary and reversible (i.e., the system adapts) or chronic and cumulative. In any case, if a coal-fired power plant has a measurable impact on the environment, there is every reason to believe that it will be registered as a diminution of community structure.

Both plant and animal diversity and energy transfer between and within trophic levels are measures of community structure. Furthermore, these functions may be regarded as important ecosystem resources. We hypothesize that the immediate population-level effects from environmental stress may result from differential impairment of competitive ability. At the relatively low pollution levels anticipated in the investigation, we may expect to find predisposing and subclinical effects that will be impossible to detect in the absence of appropriate population dynamic, biochemical, and physiologic information.

Effects need not be mediated by alterations in food chains or energy flow. Certainly food chains and mass and energy flow patterns will be affected (although possibly secondarily) whenever population adjustments occur. For example, a pollutant may alter the physiology or behavior of the individuals that comprise a population. These alterations are ultimately reflected in altered survival, reproduction and/or emigration rates. Such effects may be subtle and difficult to relate to the specific stressor. In the real world, numerous stressors are operating in complex ways with various lag times; these tend to confound the results of any field evaluation of a single stressor. The end result of the response of the community to a continued environmental stress is a readjustment of the component populations (plant and animal) at a new state of dynamic equilibrium. It is not possible to predict with any confidence, either the adjustments and mechanisms most importantly involved or the final population levels that will be reached. By studying a rather broad range of interacting variables and, in particular, by an intensive study of certain populations, some may be isolated as sensitive and reliable measures of air pollution. Table 1 outlines the existing research plan.

BASIS FOR SITING THE INVESTIGATION IN SOUTHEASTERN MONTANA

The selection of an appropriate study area was essential to structuring the entire investigation. Colstrip was selected on the basis of our initial literature review and several field trips to Montana and Wyoming. The principal criteria employed in the selection of the study area are detailed below:

1. The region is climatically and ecologically representative of a relative large portion of the North Central Great Plains.

2. The Colstrip area of the Fort Union Basin is a relatively pristine pine savanna area which has never had a stationary source of (toxic) gaseous or particulate emissions. Thus the vegetation and nonmigratory aniamls in the area, while being stressed by various environmental factors such as drought, adverse temperatures, nutrient deficiencies, etc. have never been subjected to the added stress of air pollutants. Previous air

pollution studies around power plants (e.g., the Environmental Protection Agency's Mount Storm studies; the Tennessee Valley Authority's pre- and post-operational studies; Large Power Plant Effluent Study (LAPPES) (APTD 70-2, 0589, and 0735) and others (EPA 660/3-74-011) have generally occurred after the power plants are on line, or in areas already so polluted prior to operation of the power plant that one has never been able to adequately assess the very first introduction of toxic emissions of power plants to an essentially pristine ecosystem.

3. Montana laws favor rational development of resources.

4. According to current assessments, Montana contains nearly a third of the strippable coal reserves in the northern central Great Plains. It is possible that some 120,000 acres will be stripped during the next two decades.

5. Southeastern Montana constitutes a rich rangeland resource.

6. Existing data, while extremely scarce. indicate that air quality in Eastern Montana is well above the national average.

7. Local-regional emission sources (see Regional Profile Report on Atmospheric Aspects, Northern Great Plains Resource Program, April 1974 (draft copy)) other than the coal-fired power plant at Colstrip are unlikely to contribute importantly to the air pollution burden of the Rosebud Creek Watershed during the period of investigation.

8. The projected sites and schedules of strip-mining and power plant development are known.

9. The history of human disturbance is reasonably well-documented.

10. We expect human disturbance (except that associated with coal mining and coal-conversion) to be relatively low throughout the period in investigation. We feel reasonably assured that sample sites, including buffer zones and reference sites, will remain substantially free of confounding disturbance.

11. Other investigations are underway at Colstrip that are complementary to our investigation. Our investigation will thus broaden and extend an existing data base.

SCOPE AND PURPOSE

Following one year of intensive preparation, the overall investigation is presently planned is a three-year field effort with a fourth year devoted to data analysis and evaluation. Most of the field activities during each sampling year will take place from April through October, although some components will continue through the entire annual cycle. We expect the evaluation and synthesis of our results to generate a protocol that will allow planning managers to assess the impact of energy conversion activities on grasslands in the Northern Great Plains prior to the initiation of site selection activities. Achievement of this objective would greatly enhance our ability to make valid siting and regulatory decisions. The full realization of this objective within the time frame that has been projected will require a synthesis of the National Ecological Research Laboratory's effects research data and the coordination of these with the results of socio-economic and transport/fate research projects. This will be difficult to accomplish, but the rewards are potentially great.

Table 1. Outline of The Research Plan for the Montana Coal-Fired Power Plant Project

I. Field Investigation

- A. Temporal and spatial quantitative inventory of components of the study area, with particular focus on the annual cycle phenomena of key species.
- B. Meteorological measurements to support the modeling and experimental air pollution research efforts.
- C. Development of remote sensing as a tool for detecting effects of air pollutant challenge on the ecosystem.
- D. Measurement of loss of inventory attributed to strip mining, power lines, human activity, water use, and other potentially confounding influences, e.g., pesticides, disease, population cycling.

II. Air Pollution Experiments

- A. Experimentally controlled air pollution of spatial segments of an ecosystem.
- B. Detailed measurement of biological structure and function, including energy flow, nutrient cycling and species condition, composition and diversity during and following air pollution stress.

III. Laboratory Experiments.

- A. Measurement and evaluation of physiologic, biochemical and behavioral mechanisms of response to air pollution challenge.
- B. Precise measurement of parameters that support dynamic models.
- C. Experiments designed to test whether changes observed in experimental study plots can be attributed to air pollutant stress.
- D. Secondary stresser experiments (e.g., disease, temperature stress, water stress, non-specific stress).
- E. Experiments designed to test field-generated hypotheses.

IV. Modeling

- A. Use of an ecosystem level model to describe and predict effects of air pollutant challenge.
- B. Use of models to help design experiments.
- C. Use of models to help disentangle pollutant effects from natural variation and system dynamics.
- D. Meteorlogical and dispersion modeling to describe the mode of entry of pollutant into the ecosystem and its time and space distribution and concentration.

* * *

BASELINE VEGETATIONAL STUDIES NEAR COLSTRIP

J. E. Taylor, W. C. Leininger, and R. J. Fuchs*

INTRODUCTION

This project was activated 15 July 1974 as part of a larger project sponsored by the Environmental Protection Agency (EPA) to monitor bioenvironmental effects of coal-fired electric generating plants in southeastern Montana. Our particular project objectives are:

1. To record pre-treatment native plant communities in areas likely to be affected by fossil fuel power plants and on areas to be stressed artificially with pollutants.

2. To develop measurement techniques and monitor changes in plant community structure, diversity, phenology and speciation following air pollution stress.

3. To develop detailed vegetational maps of the study areas.

4. To provide data for simulation models which can be used to predict bioenvironmental changes following fossil fuel power generation in other areas.

Due to the project's late starting date some of our objectives were not realized the first summer. When field work was initiated, many of the ephermeral plants were dried up and were either impossible to identify or gone entirely from the sites. The late date also hampered our color infrared photography and seed and plant collection of many species. The main accomplishment of the first year was the development of techniques for future studies.

The first season's work was concentrated on the experimental areas which were established for the overall EPA project. These include the proposed stressing site at Ash Creek, where grassland will be artificially fumigated, and the validation sites near Colstrip.

Additional Colstrip sites were located on three adjacent, relatively undisturbed knolls, herein referred to as pristine knolls A, B, and C (Figure 1).

The project activities to date may be classified into the following categories:

Description and Characterization of Study Areas

Plant Community Analysis

Photographic Monitoring

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*J. E. Taylor, W. C. Leininger, and R. J. Fuchs, respectively, Assistant Professor, Research Assistant, and Graduate Research Assistant, Department of Animal and Range Sciences, Montana State University, Bozeman.

Each of these activities is discussed below.

DESCRIPTION AND CHARACTERIZATION OF STUDY AREAS

Each of the study sites was described in detail. Data were recorded on exact location, topography, soils, and vegetational composition. These data are given in Table I.

Further possible sites have been examined for future use, including areas east of Colstrip and several sites on the Ashland Division, Custer National Forest.

PLANT COMMUNITY STRUCTURE

Canopy cover estimates were made on all intensively studied locations and on all three pristine knolls. The technique used was that of Daubenmire (2), which employs a 2 X 5 dm plot frame in which each species canopy cover is classified into one of six coverage categories. Fifty frames were examined on each sampling date on each site.

DIVERSITY STUDIES

Numerical data for index of diversity studies (species and individuals per species) were recorded for each Daubenmire plot concurrently with canopy cover. Diversity indices used were:

1. Shannon-Weaver Function

$$H' = \sum_{i=1}^{S} Pi \log Pi$$

Where H' = the index of diversity

S = the number of species present

Pi = the number of individuals per species divided by the total number of individuals sampled.

H' is an estimation of Brillouin's H, the true population diversity. At large sample sizes the value for H' is almost exactly that for H. In addition, since log Pi is used rarer species aren't discriminated against (6, 7).

2. Simpson's D

$$D = 1 - \sum_{i=1}^{S} Pi^2$$

Where D = the index of diversity

S = the number of species present

Pi = the number of individuals per species divided by the total number of individuals sampled.

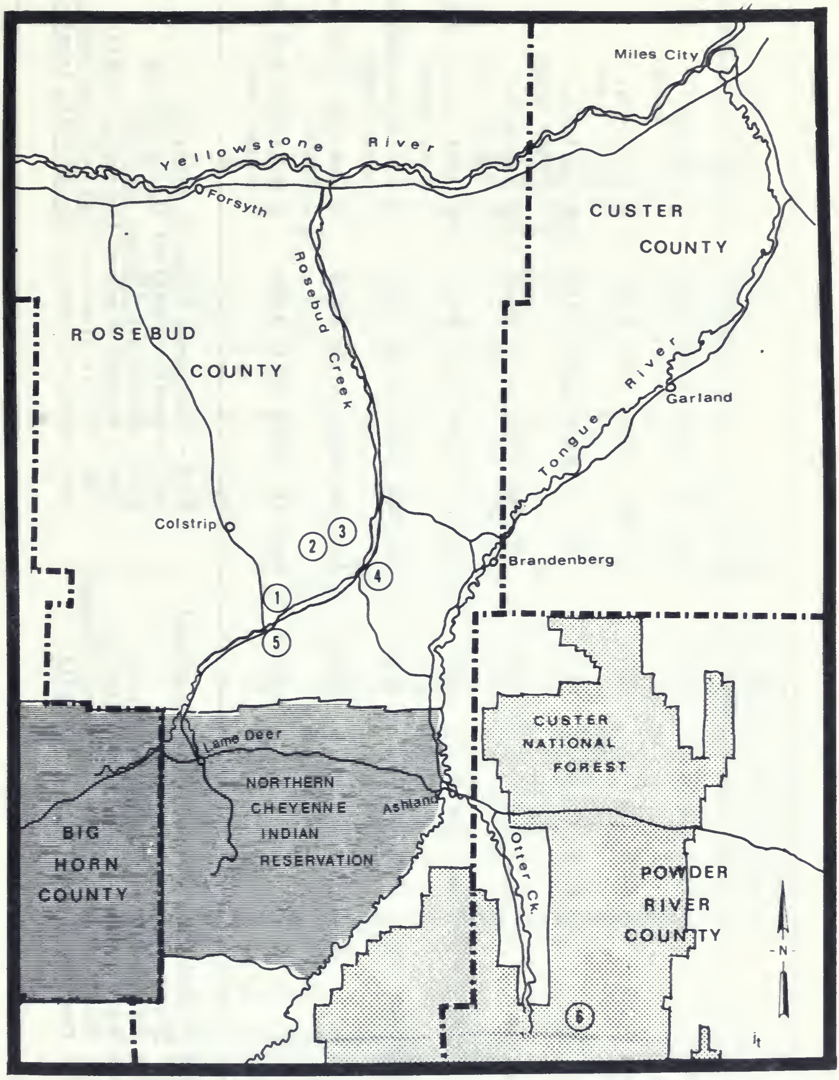

FIGURE 1. Locations of principal study sites (1=Hay Coulee, 2= Cow Creek, 3=North Pasture, 4=School Section, 5=Relict Knolls, 6=Ash Creek).

TABLE I. Characterization of Study Sites.

Name		Distance (km) & Direction fr/ Colstrip	Elevation (meters)	Slope & Exposure	Plant Aspect[1/]	Soil Characterization
Ash Creek		74.8 SE	1173	4-5% NE	AGSM, KOCR, BRJA	Residual silt loams
Hay Coulee		11.6 SE	927	4% NNE	AGSM, ARTR, KOCR, BRJA	Colluvial clay loams
Cow Creek		11.6 SE	917	6% N	STCO, AGSM, BRJA, BRTE	Colluvial sandy loams
North Pasture		14.7 E	902	5% NE	STCO, ARFR, AGSM, BRJA	Colluvial sandy loams
School Section		18.3 ESE	904	3½% NE	AGSM, BRTE, BRJA, ARFR	Residual and colluvial clay loams
Pristine Knolls	A	13.8 SE	908	2% ESE	CALO, SCSC, AGSP	Colluvial and residual sandy loams
	B		902	4½% NW	AGSP, STCO, ARTR	Colluvial and residual loams
	C		908	6½% SE	STCO, CAFI, AGSM	Colluvial and residual sandy loams

[1/] AGSM = Western wheatgrass (Agropyron smithii)
ARCA = Silver sage (Artemisia cana)
BRJA = Japanese brome (Bromus japonicus)
ARTR = Big sagebrush (Artemisia tridentata)
AGSP = Bluebunch wheatgrass (Agropyron spicatum)
CAFI = Threadleaf sedge (Carex filifolia)
KOCR = Junegrass (Koeleria cristata)
STCO = Needle-and-thread (Stipa comata)
BRTE = Cheatgrass (Bromus tectorum)
ARFR = Fringed sagewort (Artemisia frigida)
SCSC = Little bluestem (Schizachyrium scoparium)
CALO = Prairie sandreed (Calamovilfa longifolia)

While values for D agree closely with values for H', the expression Pi^2 used in the formula discriminates against the rarer species (8).

3. Redundancy

$R = (H'max-H') \quad (H'max-H'min)$

Where R = redundancy

H' = Shannon's H'

H'max+H'min are the maximum and minimum possible values, respectively, for H' based on the species and total number of individuals recorded.

Redundancy is a measure of evenness or equitability which relates the observed H' to the maximum and minimum possible values of H' given the number of species and total number of individuals present (4).

4. Probability of Interspecific Encounter (P.I.E.)

$$\Delta_1 = \left[\frac{N}{N-1}\right] \quad 1 - \sum_{i=1}^{S} Pi^2 = \left(\frac{N}{N-1}\right) D$$

Where Δ_1 = the probability of interspecific encounter (P.I.E.)

D = Simpson's D

N = the total number of individuals sampled.

P.I.E. is an index of diversity based on Simpson's D. It is the probability an individual has of encountering an individual of another species (5).

5. Probability of Intraspecific Encounter (Pa)

$Pa = 1 - \Delta_1$

Where Pa = the probability of intraspecific encounters

Δ_1 = P.I.E.

Pa is the complement to P.I.E. (5). It measures the probability an individual has of encountering another individual of the same species in the population sampled.

6. P.I.E. Transformation (Δ_3)

$$\Delta_3 = 1/ \sum_{i=1}^{S} Pi^2$$

Where Δ_3 = P.I.E. transformation

$\sum_{i=1}^{S} Pi^2$ = the expression from Simpson's D.

The P.I.E. transformation is used to increase the spread between values for Simpson's D at the upper portion of its range (5).

7. Fisher's α

$$\alpha = \frac{N(1-X)}{X};\ N = \frac{n_1}{1-X}$$

Where α = the index of diversity

N = the total number of individuals sampled

n_1 = number of species with just one individual.

Fisher's α is based on the number of species in the sample containing only one individual (3).

A comparison of the various indices is given in Table II. Statistical tests of correlation appear in Tables III and IV. It should be noted that all indices were calculated on a site-by-site, not frame-by-frame basis. Thus, standard errors are not presented.

As can be seen from Tables II, III, and IV, the various indices are correlated quite closely except for Fisher's α. The high value for H' for the Ash Creek site is probably due to a greater number of forbs, reflecting the more favorable plant habitat.

Additional data are needed to see if the various indices used are sensitive enough to show variations in diversity through the growing season. Once enough background data have been gathered and analyzed, it will be seen if the indices can monitor changes in diversity due to air pollution stresses on the ecosystem.

SITE SIMILARITY COMPARISONS

Frequency data from all sites were used to construct a similarity matrix, using the relationship

$$I = \frac{2W}{a+b},$$

Where I = Index of Similarity,

W = the sum of frequencies in common between two stands (sites)

a = the sum of frequencies of the first stand

TABLE II. Comparison of various Indices of Diversity, based on plant numbers.

Site	Fisher's α	Simpson's D	H'	Redundancy	P.I.E.	Pa	$\triangle_3$
North Pasture	3.0382	.8765	1.0506	.2808	.8768	.1232	8.0972
Hay Coulee	5.0052	.8585	.9804	.3275	.8587	.1413	7.0671
Cow Creek	5.0053	.8433	.9464	.3516	.8435	.1565	6.3816
Ash Creek	2.0010	.8423	1.0590	.3547	.8425	.1575	6.3412
School Section	6.0112	.8194	.8886	.3948	.8196	.1804	5.5371

TABLE III. Spearman Rank Correlation Coefficients, based on plant numbers.

	D	H'	R	P.I.E.	Pa	$\triangle_3$
D	-	0.4	-1.0	1.0	-1.0	1.0
H'	0.4	-	-0.4	0.4	-0.4	0.4
R	-0.1	-0.4	-	-1.0	1.0	-1.0
P.I.E.	1.0	0.4	-1.0	-	-1.0	1.0
Pa	-1.0	-0.4	1.0	-1.0	-	-1.0
$\triangle_3$	1.0	0.4	-1.0	1.0	-1.0	-

TABLE IV. Pearson's Product of Moments Correlation Coefficients, based on plant numbers.

	D	H'	R	P.I.E.	Pa	$\triangle_3$
D	-	0.4	-1.0	1.0	-1.0	1.0
H'	0.4	-	-0.4	0.4	-0.4	0.4
R	-1.0	-0.4	-	-1.0	1.0	-1.0
P.I.E.	1.0	0.4	-1.0	-	-1.0	1.0
Pa	-1.0	-0.4	1.0	-1.0	-	-1.0
$\triangle_3$	1.0	0.4	-1.0	1.0	-1.0	-

b = the sum of frequencies of the second stand (9).

The similarity matrix was the basis for a two dimensional ordination (1) and a cluster dendrogram (9). The ordination (Figure 2) and the dendrogram (Figure 3) show a reasonably high degree of similarity among all sites. Further, the sites fall into three major groupings: Ash Creek and Hay Coulee; Cow Creek, North Pasture, and School Section; and the three relict knolls. The overall I-value of 52.5 indicates a reasonable level of comparability among the study sites.

PHENOLOGY

Initial observations were made to test a phenological scorecard which was developed for this project. The lateness of the season precluded the development of an annual phenologic profile for the study areas, but it was felt that the system will be useful in subsequent seasons.

The phenological stages recognized are shown in Table V.

PLANT COLLECTION

The field crew collected all plant species on each study site as they came into flower. This included only the late flowering species this year. Future collections will obtain specimens of the early flora. This material will constitute a local reference herbarium for consultation by field workers. Specimens also will be submitted to the Montana State University Herbarium for taxonomic verification and voucher purposes.

SEED COLLECTION

Seeds of common plant species were collected as time permitted. This material will be used by the bird and mammal research personnel in examining food habits of their animal populations. This work will continue in future years.

PERMANENT GROUND PHOTO PLOTS

Initial photo plots were established and photographed at all locations. At Ash Creek, two plots were placed in each of the proposed stressing plots. At the Hay Coulee, Cow Creek, North Pasture, and School Section sites, two photo plots were established in each exclosure, and one photo plot was placed on each of the three pristine knolls.

The photo plots were 3 X 3 feet in area, and were marked for relocation. Each was photographed in color from a high oblique angle (25° from vertical). Steroscopic photography was used for ease of plant identification. Most of the plots also were photographed with infrared color film. After the oblique photographs were made, the camera was tilted up so that the field of view included the horizon, and an aspect picture was taken. At the same time as the plot photography, a rough chart was prepared of the plot, showing locations and identifications of the various species present. This was done to aid in the interpretation of the photographs this winter. An example sterogram is shown in Figure 4.

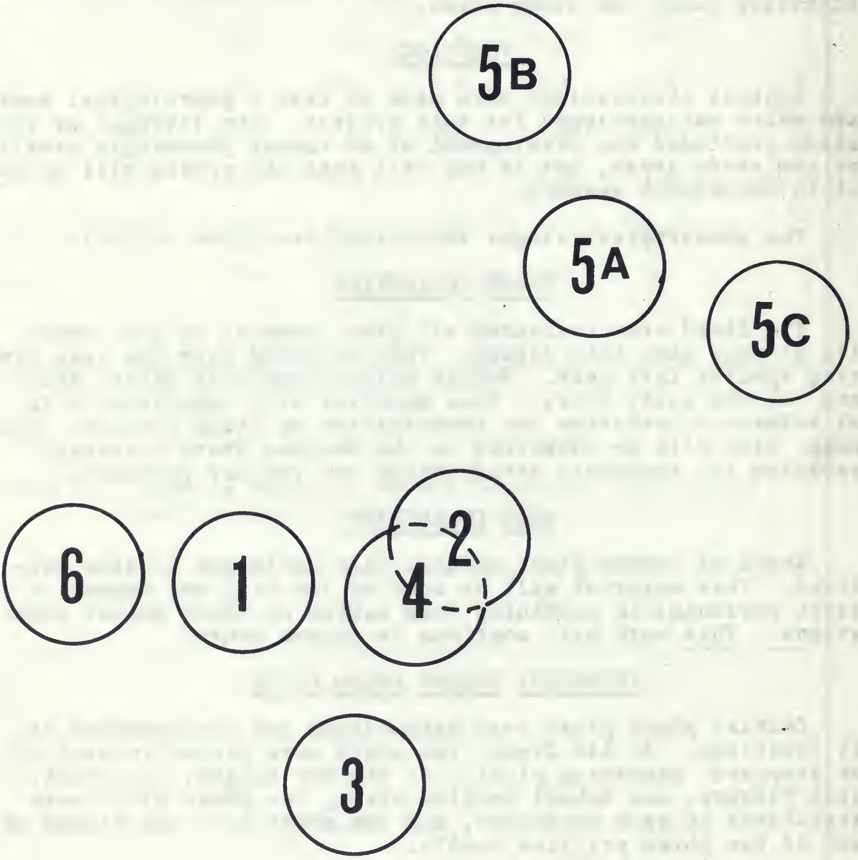

Figure 2. Ordination of Intensive Sites, based on Indices of Similarity (frequency). 1 = Hay Coule; 2 = Cow Creek; 3 = North Pasture; 4 = School Section; 5 = Relict Knolls; 6 = Ash Creek.

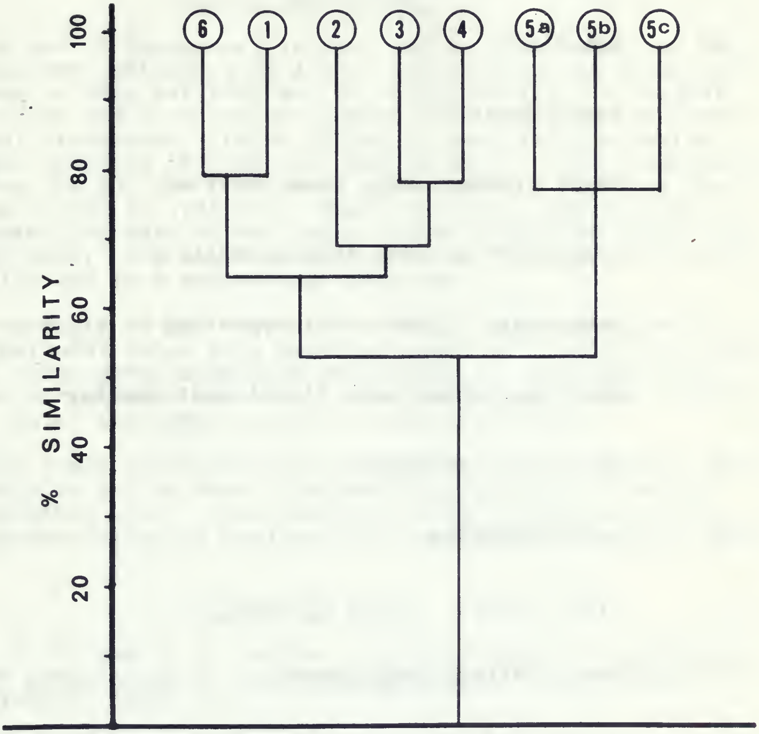

Figure 3. Dendrogram of similarity indices for the intensive sites, based on frequency. (1 = Hay Coulee; 2 = Cow Creek; 3 = North Pasture; 4 = School Section; 5 = Relict Knolls; 6 = Ash Creek.)

TABLE V

PHENOLOGY CODE

CODE	STAGES
1	Cotyledon (newly germinated)
2	Seedling
3	Basal Rosette
4	Early greenup, veg. buds swelling
5	Vegetative growth, twig elongation
6	Boot stage, flower buds appearing
7	Shooting seed stalk, floral buds opening
8	Flowering, anthesis
9	Late flowering
10	Fruit formed
11	Seed shatter, dehiscence
12	Vegetative maturity, summer dormancy, leaf drop
13	Fall greenup
14	Winter dormancy
15	Dead

Enlargements (8" X 10") of permanent plot photographs are being interpreted by making species overlays. These will constitute baseline maps of the monitoring stations, and will be used in subsequent years to follow changes in species composition and cover.

Some of the plot photographs are being charted in three dimensions, using a computer plotting procedure. This will be evaluated as to its usefulness in plant monitoring.

AERIAL PHOTOGRAPHY

On 24 and 25 September, initial aerial photography of the study areas was contracted to Aerial Survey, Inc. of Miles City. The purpose of this activity was to obtain imagery in various emulsion types and at different scales for evaluation as future operational procedures. Color IR color, and black-and-white imagery was obtained in 35mm and 70mm formats. Flying elevations ranged from 500 to 7200 feet above ground level, yielding image scales from 1/3000 to 1/44,500. Black-and-white index mosaics were prepared for each of the study areas as aids to future aerial photography. The color imagery will be examined further in terms of its use as a monitoring technique.

Enlargements of Hay Coulee 70mm aerial photographs show that conventional color at a negative scale of 1:3000 will yield prints of 1:500 with sufficient resolution to map plant communities and conspicuous species. These photographs also show impacts of travel and sampling in the exclosure area.

Medium scale (1:10,000) aerial photography was viewed stereoscopically to aid in exact placement of exclosure sites on USGS topographic maps. This imagery proved useful as a guide to the interpretation of smaller scale photography acquired elsewhere.

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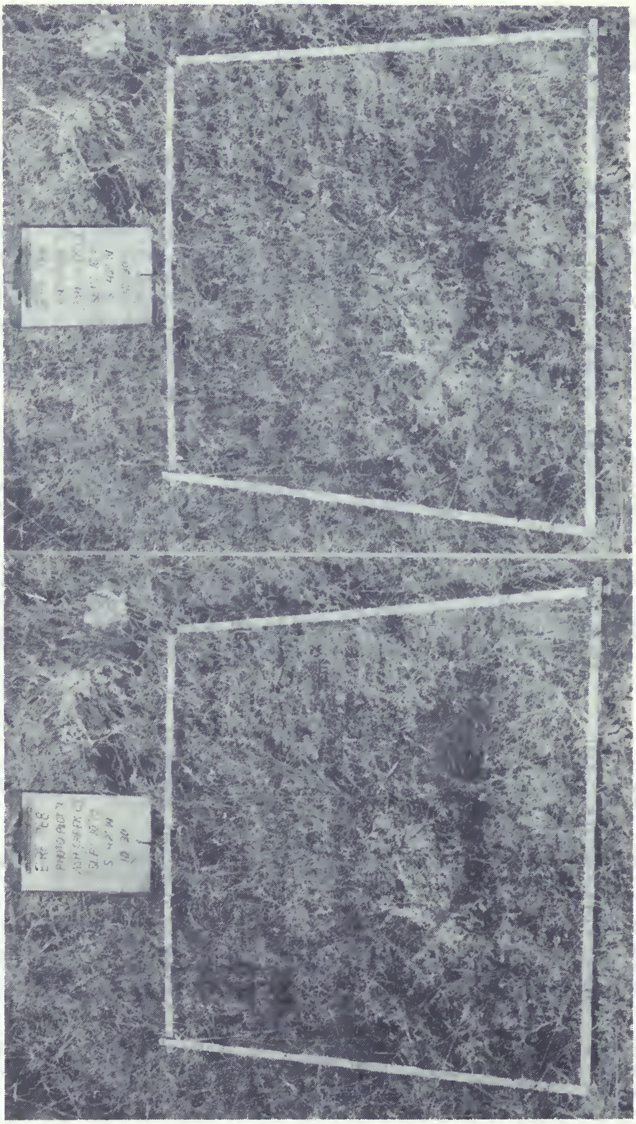

Figure 4. Example steorgram.

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A REMOTE SENSING STUDY TO DETERMINE ECOSYSTEM EFFECTS FROM STACK EMISSIONS FROM A POWER PLANT, COLSTRIP, MONTANA

Thomas R. Osberg, Robert A. Lewis, and John E. Taylor*

The National Ecological Research Laboratory of the U.S. Environmental Protection Agency is conducting a program of field studies in the vicinity of the coal-fired power plant near Colstrip, Montana. The purpose of this program is to measure and predict change in a grassland ecosystem as a function of air pollution and associated environmental parameters (3). As a key element of this program we are developing and applying remote sensing as a tool for (a) detecting effects of air pollutant challenge on the ecosystem, and (b) measuring the loss of inventory that results from strip mining, power lines, increased human activity, water use and other potentially confounding influences such as pesticides, disease, and population cycling.

We expect the remote sensing component to provide us with information that confirms and extends information gained from our ground-based studies. High resolution camera systems installed in both high performance, high-altitude aircraft and in low-flying craft should provide us with an excellent permanent temporal record of the study areas. Such repetitive coverage of a particular ground area or target is an established technique for detecting changes in both natural and man-made features of the environment (1).

We are evaluating several kinds of photography (color, color IR, and monochrome) at varying scales (1:2000 to ERTS) as tools for the assessment of air pollution impact from the power plant at Colstrip, Montana, and the effects of SO_2 effects on our field experimental plots on Custer National Forest in southeastern Montana (3). Our work has shown that 70 mm color at a negative scale of 1:3000 yields sufficient resolution for most vegetation work. Whereas during 1974 our work was primarily developmental, we are now prepared to apply the most appropriate procedures to biological effects monitoring (see also 4).

The high altitude photography employed ranged in scale from 1/35,000 to scales in excess of 1/80,000. High altitude photography provides synoptic coverage, and is most suitable for analysis of natural features in large areas, as well as for mapping purposes. Conversely, low altitude flights yield imagery with scales of 1/3000 to 1/44,500. This photography is essential in obtaining detailed information of selected small targets on the ground.

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A series of three to six low level flights is planned for 1975. The low level flights are timed to coincide with key periods of the growing cycle. Both color and color infrared emulsions will be used. The sensor system, consisting of two Hasselblad cameras, yields a frame format of 70 x 70 millimeters. We expect to acquire photography at scales as large as 1:2000. We believe that a sufficient level of detail is provided by this imagery to enable us to trace and describe pollution stress patterns which may develop in vegetation discernible in the imagery. Repetitive coverage of the field study sites will be performed using this large-scale imagery. Information from this source, together with ground data collected at the field study sites, will aid the overall program in assessing microclimatic and air pollution patterns and effects.

We designed the high-level photography to provide us with baseline data for vegetation and landform mapping including a seasonal record of vegetational community composition. Information on microclimates and moisture gradients is also desired. Such information will include records of subirrigated and run-in moisture areas; erosion, if any; snow melt patterns; and drainage patterns. We hope also to record infrared signatures of individual plant species and plant communities. The high altitude photographs will also provide information on grazing use patterns, and winter game use, and the numbers of large game. The low-level (1000 feet) photography will provide more detailed information on specified sites and is expected to bridge the gap between high-level and ground-level records..

Early in the program we were able to acquire imagery from four high altitude missions of the Colstrip area. All of the photographs from these missions are color infrared and were taken during the summers of 1972-73 and 1974. They cover, in the aggregate, more than 10,000 square miles in the vicinity of Colstrip. This photography represents an important source of baseline information of the area, prior to operation of the power plant. The photography was loaned to EPA and the photolab at the Environmental Photographic Interpretation Center (EPIC) recently complete duplication of these films. Table 1 summarizes the coverage information for this imagery.

Two high altitude flights will be made for us by the National Aeronautics and Space Administration in 1975. Both color and color infrared films with nine inch frame format will be used for these missions. Coverage is planned for an area in a one degree cell: 46 to 47 degrees north by 106 to 107 degrees west (See Figure 1). I includes the power plant and mines at Colstrip and our field study sites located east and southeast of Colstrip. The missions are scheduled for early May and mid-summer to coincide with critical periods of the growing season. A nominal scale of 1/40,000 is expected for this photography.

Field study sites for the program have been established at two general locations near Colstrip. Some five sites are situated within a 20 kilometer (12 mile) arc to the east and south of the power plant (see Figure 2). The second group of sites is near the Fort Howes Ranger Station, about 75 kilometers (47 miles) from Colstrip (Figure 3). The field sites include three about 25 acres in size, at which experimental fumigation of

TABLE 1

HIGH ALTITUDE PHOTOGRAPHY OF SOUTH EASTERN MONTANA

AREA OF COVERAGE	DATE	SCALE	ORIGINATING AGENCY
Rosebud-Coalwood Planning Unit	28 June 1974	1/80,000	Bureau of Land Management, U. S. Department of Interior
Decker-Birney Planning Unit	1 June 1972	1/40,000	Bureau of Land Management, U. S. Department of Interior
Northern Cheyenne Eastern One-Third of the Crow Indian Reservations	4-5 July 1973	1/40,000	Bureau of Indian Affairs, U. S. Department of Interior
Custer National Forest Ashland/Fort Howes District	28 August 1973	1/36,000	U. S. Forest Service, U. S. Department of Agriculture

TOTAL AREA: Over 10,000 square miles or 2,590,000 hectares.

grassland communities is planned. A major goal of our remote sensing is to record the stress patterns that occur at the field experimental sites over a protracted length of time.

ACKNOWLEDGEMENTS

Photography from the four high altitude overflights of the Colstrip region was acquired within the past three years by other Federal agencies based in Billings. We want to acknowledge the efforts of the people responsible for lending this invaluable imagery to us. Mr. Fred Batson and Mr. Ed Zaidlicz of the Montana office, U. S. Bureau of Land Management, loaned us coverage of two BLM management planning areas Rosebud-Coalwood and the Decker-Birney. Messrs. Paul Kipp and Keith Beartusk, Bureau of Indian Affairs, Billings and Lame Deer, Montana, made available their holdings of Indian lands near Colstrip; and the U.S. Forest Service Office in Billings furnished their photography of the Ashland Division, Custer National Forest. Our sincerest appreciation is extended to all members of their staffs who assisted the Environmental Protection Agency's remote sensing project.

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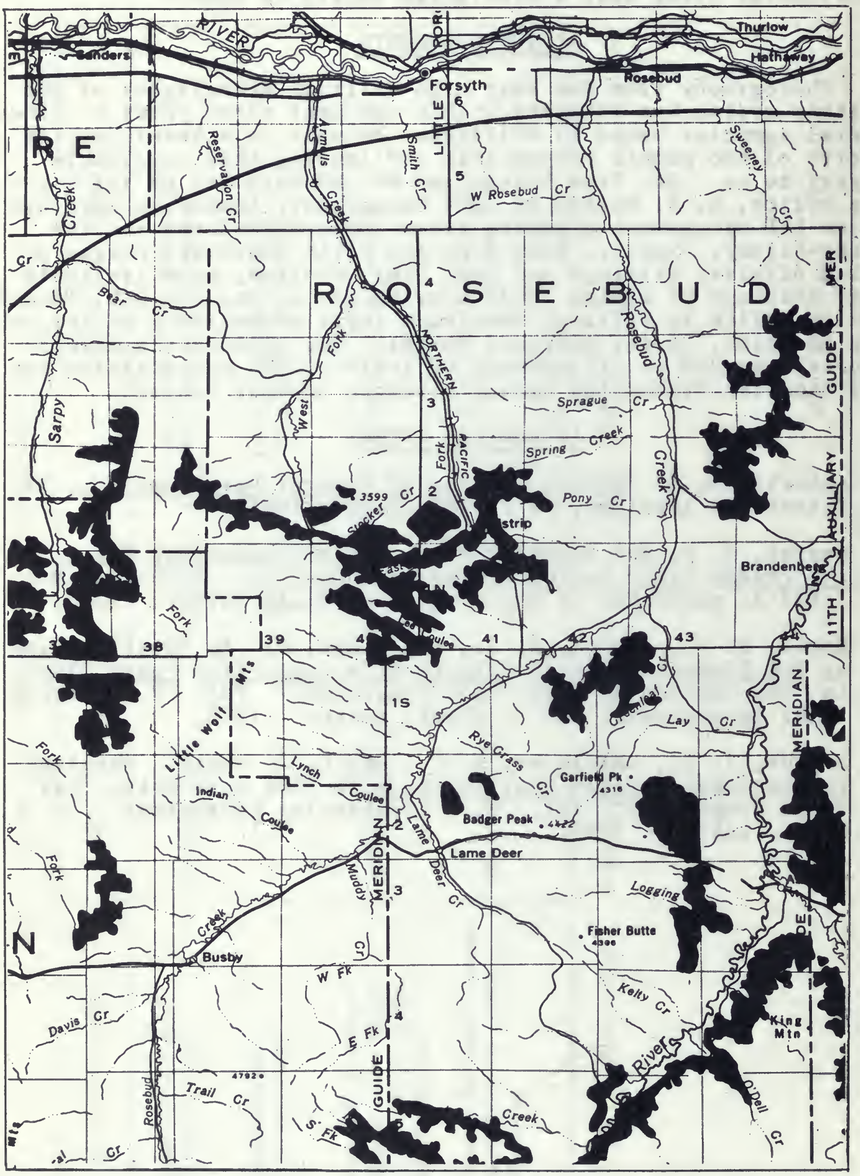

FIGURE 1. The Colstrip Power Plant is based on an extensive deposit of coal reserves. Nearly all of the area surrounding the plant has been photographed by high altitude imagery since 1972. Original map scale 1:500,000. USGS Map 1-847A.

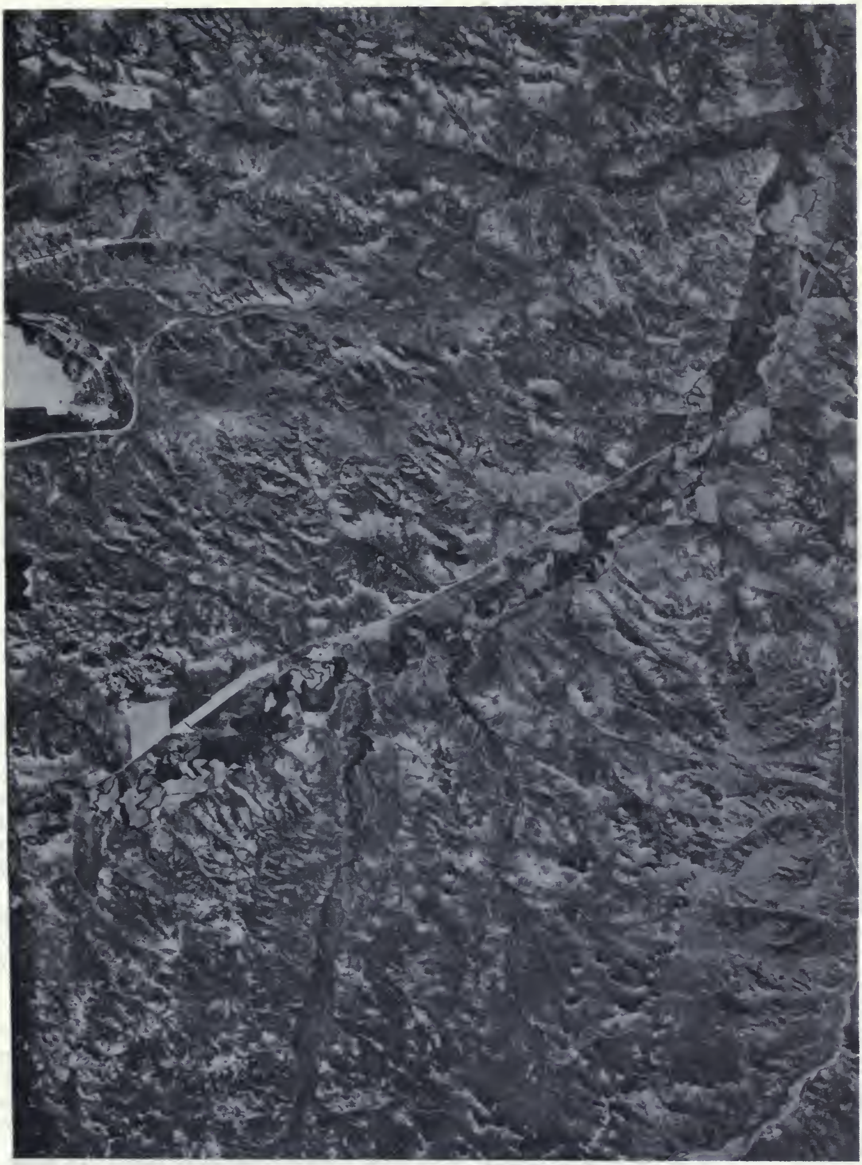

FIGURE 2. Air photograph of the area immediately east and south of Colstrip. A portion of the strip mines is visible as white tone at the left margin. Stream valleys appear as dark-toned meandering features. A number of field study sites lie between the mine and Rosebud Creek, seen flowing from southeast to north through the center of the photograph. Original scale: 1:80,000. Acquired 28 June 1974 by U.S. Bureau of Land Management.

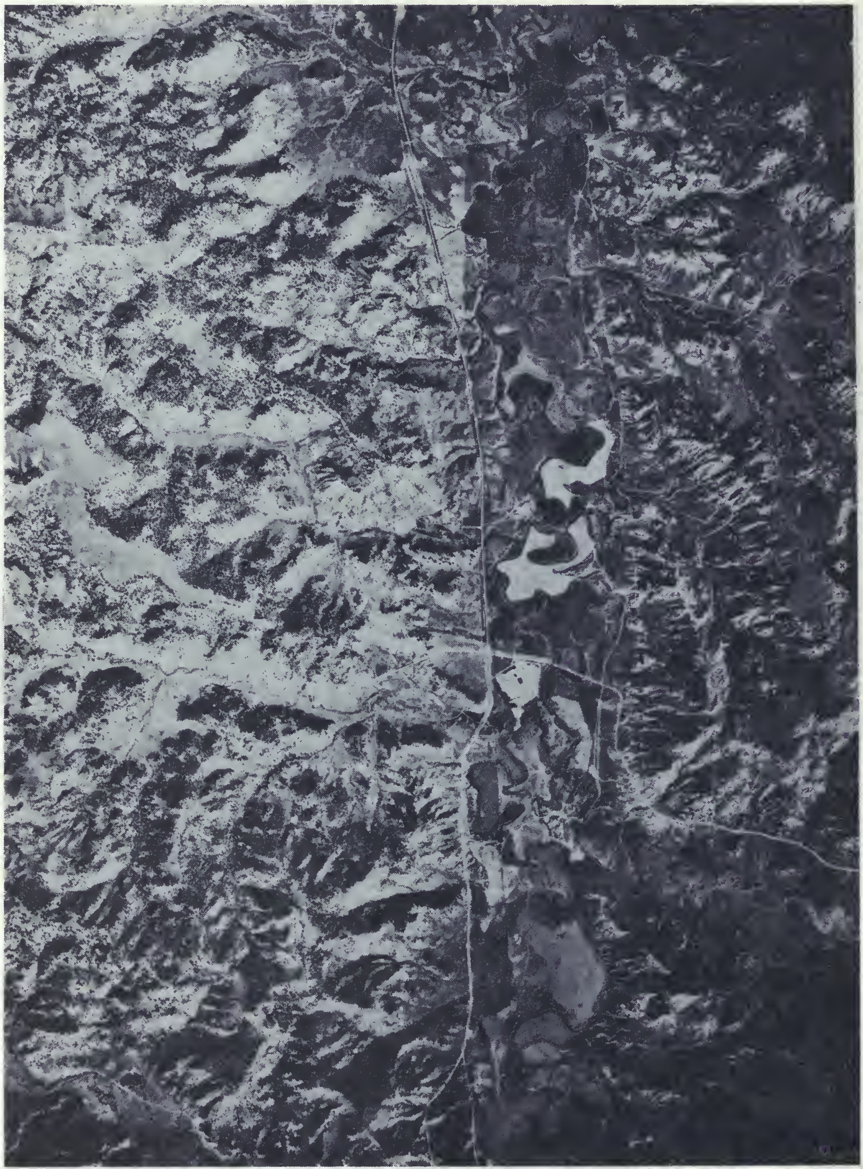

FIGURE 3. Field study sites in the vicinity of the Fort Howes Ranger Station are some 75 kilometers south-southeast of the power plant at Colstrip. Fort Howes is near the center of the photograph. Original scale; 1:80,000. Source: U.S. Bureau of Land Management, June 28, 1974.

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BIOMASS DYNAMICS AND PRIMARY PRODUCTION IN MIXED PRAIRIE GRASSLANDS IN SOUTHEASTERN MONTANA: BASELINE DATA FOR AIR POLLUTION STUDIES

W. K. Lauenroth, J. L. Dodd, R. K. Heitschmidt
and R. G. Woodmansee*

INTRODUCTION

The extensive grasslands of southeastern Montana have been, until recently, the single most valuable resource in the region. With the crisis in energy supplies, coal, another important resource in the region, is assuming increased importance, thus raising questions concerning the conflict between the two resource uses. This paper reports on primary producer biomass dynamics and productivity for four sites within 20 km of an emission source, and for another site located at a distance of 60 km. The data for this report, from 1974, represent an estimate of baseline conditions for the sites from the year previous to the year of activation of the first of two and possibly four generating plants at Colstrip. Our project is part of a large total system study described by Lewis et al. (10). The research reported here is concerned with the characterization of the mixed-grass prairie in southeastern Montana. This characterization is the first phase of studies which are intended to assess the effects of atmospheric emissions from a large coal-burning electrical plant on the mixed-grass prairie.

Our long-term study plan is to determine the effect of the emissions on primary producer biomass dynamics and productivity by comparing pre-emission measurements (ecosystem characterization) with similar measurements taken for two or possibly more years following activation of a nearby coal-fired generating plant complex. The four study sites have been established that, according to unpublished diffusion model predictions (Allen Lefohn and Robert Lewis, *personal communication*), will be exposed to a gradient of atmospheric pollution from the generating plants located at Colstrip, Montana. The sites are located at varying distances southeast of the generating plant. The direction of the prevailing winds are from the northwest.

Measurements of producer biomass dynamics and net production have not been previously reported for the mixed prairie in southeastern Montana. Several studies in this region have described structural characteristics (11, 19) and responses to various grazing treatments (5, 6). Net primary production and intraseasonal biomass dynamics have been reported for the mixed prairie in North Dakota (8) and South Dakota (3, 9).

Understanding the intraseasonal dynamics of primary producers and the net production of the grasslands will be an important link in understanding the effects of power plant emissions on the mixed prairie ecosystem.

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SITE DESCRIPTION

The study areas are located within the mixed prairie region of southeastern Montana. Four sites are near Colstrip in Rosebud County (Hay Coulee, Kluver West, Kluver North, and Kluver East) while the remaining site is approximately 64 km southeast in the Fort Howes Division of Custer National Forest in Powder River County. All five sites were fenced to exclude livestock prior to the 1974 grazing season. Taylor et al. (14) estimated the range condition of the sites as good to low good according to the method utilized by the Soil Conservation Service (13).

The mixed prairie has been characterized as a mixture of mid- and shortgrasses (17). Dominant grass species in the southeastern Montana region include western wheatgrass, (*Agropyron smithii*), needle-and-thread grass (*Stipa comata*), green needlegrass (*Stipa viridula*), prairie June grass (*Koeleria cristata*), and Sandburg bluegrass (*Poa secunda*). Other characteristic species include Japanese brome (*Bromus japonicus*), needleleaf sedge (*Carex eleocharis*), blue grama (*Bouteloua gracilis*), Hood's phlox (*Phlox hoodii*), common salsify (*Tragopogon dubius*), and fringed sagewort (*Artemisia frigida*).

The topography of the study region consists of steep rising buttes, and broad gently sloping valleys. The steeper buttes support *Pinus ponderosa-Juniperus scopolorum* communities whereas the hillsides and valleys are dominated by grasslands. The grassland soils were derived from parent material deposited as outwash from the surrounding buttes. Each site's geographical location, slope, aspect, elevation, soil texture, and dominant species are presented in Table 1.

The Northern Plains climate is characterized as semiarid, continental, and extremely variable (15). Long-term climatological records (T. Weaver, *personal communication*) from near Colstrip reveal a mean annual precipitation of 396 mm with approximately 50% falling during the spring growing months of April, May, and June. The mean monthly maximum temperature ranges from 32° C in July to 1° C in January with mean minimum temperatures approximately 17° C less. The average frostfree period is approximately 130 days beginning in mid-May (4).

METHODS

Above ground and below ground plant biomass was sampled by the harvest method on six dates at the Colstrip sites (10 May, 15 June, 1 July, 24 July, 12 August, and 26 September) and two dates at the Ash Creek site (3 June and 10 July). On each date five circular 0.5-m^2 quadrats were clipped on each of two replicates at the Colstrip sites and on each of eight replicates at the Ash Creek site[1]. All aboveground biomass was separated by species and into the following categories: current live, recent dead (current year's production), old dead (previous year's

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[1] The original design of the experiment included an SO_2 fumigation experiment on the Ash Creek site. For that purpose four 1-acre plots were located within the 27-acre exclosure. Since that experiment has been relocated, the data are treated as eight replicates of the same site.

Table 1. Location, slope and aspect, elevation, soil type, and dominant plant species for five mixed prairie sites in southeastern Montana[1]

Sites	Location	Slope and Aspect	Elevation	Soils	Dominant Species[2]
Hay Coulee	12 km southeast of Colstrip	4% North	930 m	Clay loam	*Agropyron smithii* *Bromus japonicus* *Bouteloua gracilis* *Artemisia frigida* *Tragopogon dubius*
Kluver West	12 km east-southeast of Colstrip	6% North	920 m	Sandy loam	*Stipa comata* *Bromus japonicus* *Agropyron smithii*
Kluver North	15 km east-southeast of Colstrip	5% Northeast	900 m	Sandy loam	*Artemisia frigida* *Stipa comata* *Agropyron smithii* *Bromus japonicus* *Tragopogon dubius* *Bouteloua gracilis*
Kluver East	19 km east-southeast of Colstrip	3½% Northeast	900 m	Clay loam	*Agropyron smithii* *Artemisia frigida* *Bromus japonicus* *Stipa comata*
Ash Creek	64 km southeast of Ashland	4-5% Northeast	1170 m	Silt loam	*Agropyron smithii* *Koeleria cristata* *Calamagrostis montanensis* *Bromus japonicus* *Artemisia cana*

[1] Site description after Taylor et al. (14).

[2] Based on harvest data in 1974.

production), and perennial live. Species or categories estimated to make up less than 1 g in any quadrat were not harvested. All harvested material was oven-dried at 60°C to a constant weight.

Litter biomass was collected with a vacuum cleaner after the standing biomass was removed. These samples were later rinsed with water, ovendried, weighed, and ashed. All litter weights are expressed on an ash-free basis.

Belowground biomass was sampled from each harvested quadrat by means of three soil cores, 7.5 cm in diameter × 10 cm deep on each sample date. In addition to this on 27 July 10 cores 5 cm in diameter × 60 cm deep were taken on each site to assess the vertical distribution of belowground biomass. These soil cores were separated into 10-cm increments. Roots were removed from the soil cores by the method of Lauenroth and Whitman (7). The samples were then oven-dried, weighed, and ashed. Belowground biomass is reported on an ash-free basis.

RESULTS

Aboveground Biomass

Seasonal dynamics of total current live (CL), recent dead (RD), and old dead (OD) for the Colstrip sites is presented in Fig. 1. Dynamics of the three categories was similar across sites. The peak in CL occurred on 15 June for all sites and all peaks were approximately 100 g/m^2. Differences among the sites in CL biomass were evident following the peak. Current live biomass declined steadily on the Hay Coulee and Kluver West sites until the last sample date. For Kluver East and Kluver North CL remained at a high level until mid-August.

Recent dead biomass increased throughout the season on all sites. The sites with a faster decline in CL also had a faster increase in RD. In all cases RD peaked on the final date. Old dead which represents biomass carried over from previous growing seasons showed a peak early in the season and declined subsequently.

An overview of the dynamics of total biomass by categories indicates a high degree of similarity among sites. The seasonality of all sites is similar to other northern mixed prairie sites for which data are available (3, 8, 9).

Analysis of primary producer biomass dynamics by individual species should maximize the amount of information conveyed to the reader. However, the variability associated with estimates of individual species biomass limits discussions to the most abundant species. For this reason we have placed emphasis on discussion of biomass dynamics by phenologically similar growth form groups (viz. cool season grasses, warm season grasses, cool season forbs, warm season forbs, half-shrubs). Cool season species make the largest portion of their growth in spring and early summer, and warm season species make their maximum growth in summer and early fall. An additional reason for combining the data into groups is that cool season species have been found in general to have the C_3 Calvin-Benson pathway of CO_2 fixation while warm season species have the C_4 dicarboxylic acid pathway

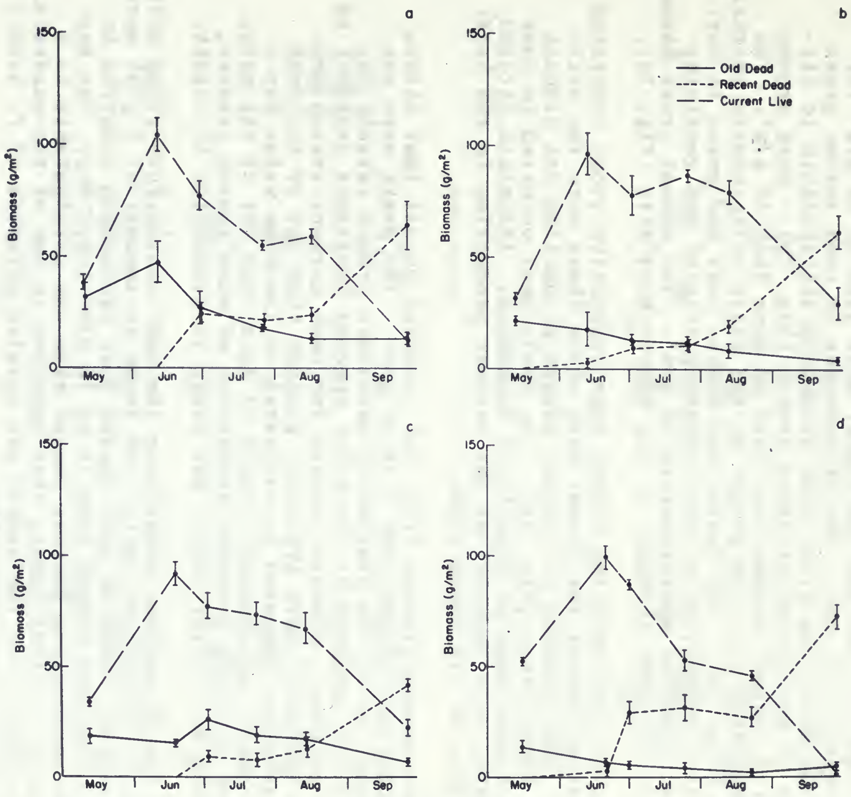

Fig. 1. Seasonal dynamics of current live, recent dead, and old dead biomass for the four Colstrip sites in 1974: (a) Hay Coulee, (b) Kluver North, (c) Kluver East, and (d) Kluver West.

(18). The significance of this for the mixed prairie is that C_3 plants have a lower temperature optimum for photosynthesis than C_4 species (18) and hence their maximum growth is during the cooler portion of the growing season. This implies that this method of grouping approximates functional groups.

Cool season grasses were the most important group occurring on the sites. Figure 2 represents the dynamics of current season production (CL + RD) for cool season grasses and the three most important species comprising this group. Peaks in cool season grass production occurred during June and July in 1974 and ranged from 100 g/m² for the Kluver West site to 55 g/m² for Kluver North (Fig. 2a). The differences in cool season grass production among the sites were primarily attributable to differences in production of *Stipa comata* (Fig. 2b). Peak production for *S. comata* ranged from zero to more than 50 g/m². The sites separated into two groups on the basis of *Agropyron smithii* biomass (Fig. 2c). Hay Coulee and Kluver East had peaks in current season production of approximately 40 g/m² and remaining sites had peaks of approximately 20 g/m². The annual grass *Bromus japonicus* was most abundant on the Kluver West site (Fig. 2d).

Half-shrubs were the second most productive group occurring on the sites except for Kluver West where there were few half-shrubs. The dynamics of current season production was bimodal for all three sites (Fig. 3a). The early peak occurred in June and the second peak in August and September. *Artemisia frigida* contributed more than 80% of the current production in the half-shrub group on all three sites.

Warm season grasses (Fig. 3b) occurred on all four sites. Peak production ranged from 4 to 16 g/m². The peaks were not as distinct as in the previously mentioned groups largely because of the tendency of the major species *Bouteloua gracilis* to grow in patches. Standard errors for peak current season production estimates were typically greater than 25% of the mean for *B. gracilis* compared to estimates of the same value for *A. smithii* which had standard errors of less than 25% of the mean. The sites with the greatest production of warm season grasses, Hay Coulee and Kluver North, had peaks in production in August.

Of the 24 species comprising the cool season forb group only one species *Tragopogon dubius* was found in amounts of 1 g or more on all sites. Peaks in cool season forb production occurred in June and July and ranged from 10 to 16 g/m² (Fig. 3c). The August peak measured on the Hay Coulee site was attributable to a dense patch of *Phlox hoodii* that occurred in one of the quadrats. We do not feel that the sample was a valid estimate of *P. hoodii* production for the entire site.

Warm season forbs were the least productive group with no one species occurring in amounts of 1 g or more on all sites. Peak production ranged from 0.14 to 3.5 g/m². No figure is presented for this group since measurable biomass was not encountered on all sites for several of the sample dates.

Since the Ash Creek site was sampled only twice during the 1974 season, no figures of these data are presented. Judging from the results from the other sites, we assume that the two

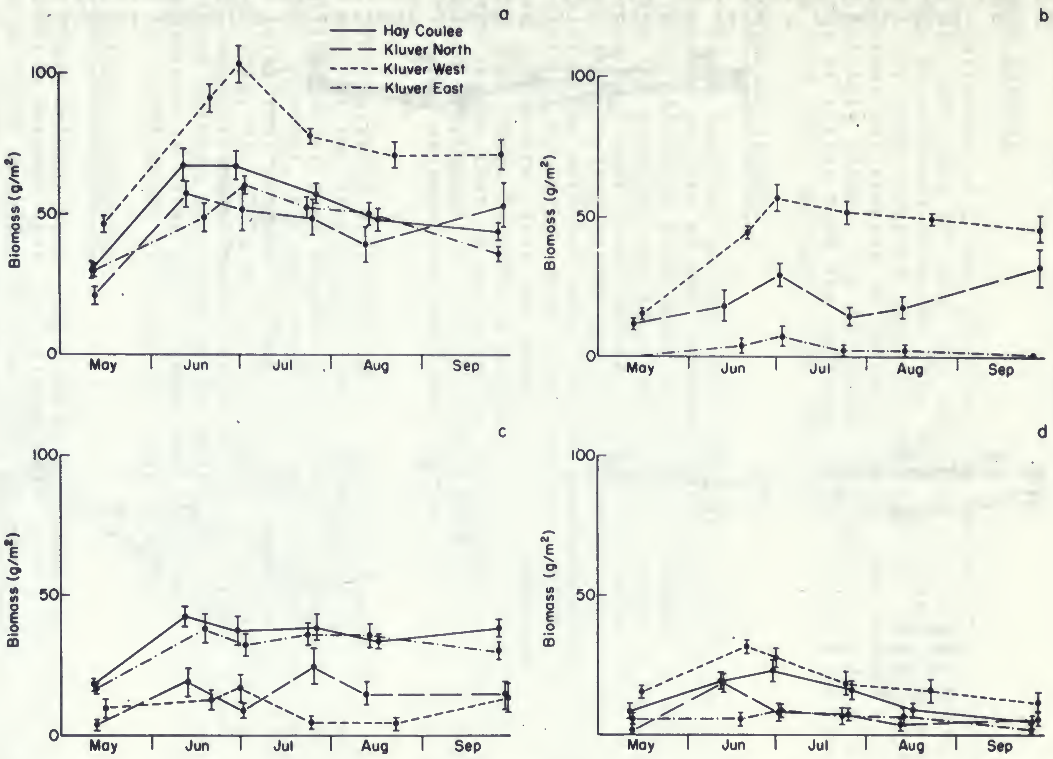

Fig. 2. Seasonal dynamics of current production (current live + recent dead) of (a) cool season grasses, (b) *Stipa comata*, (c) *Agropyron smithii*, and (d) *Bromus japonicus* for the four Colstrip sites in 1974.

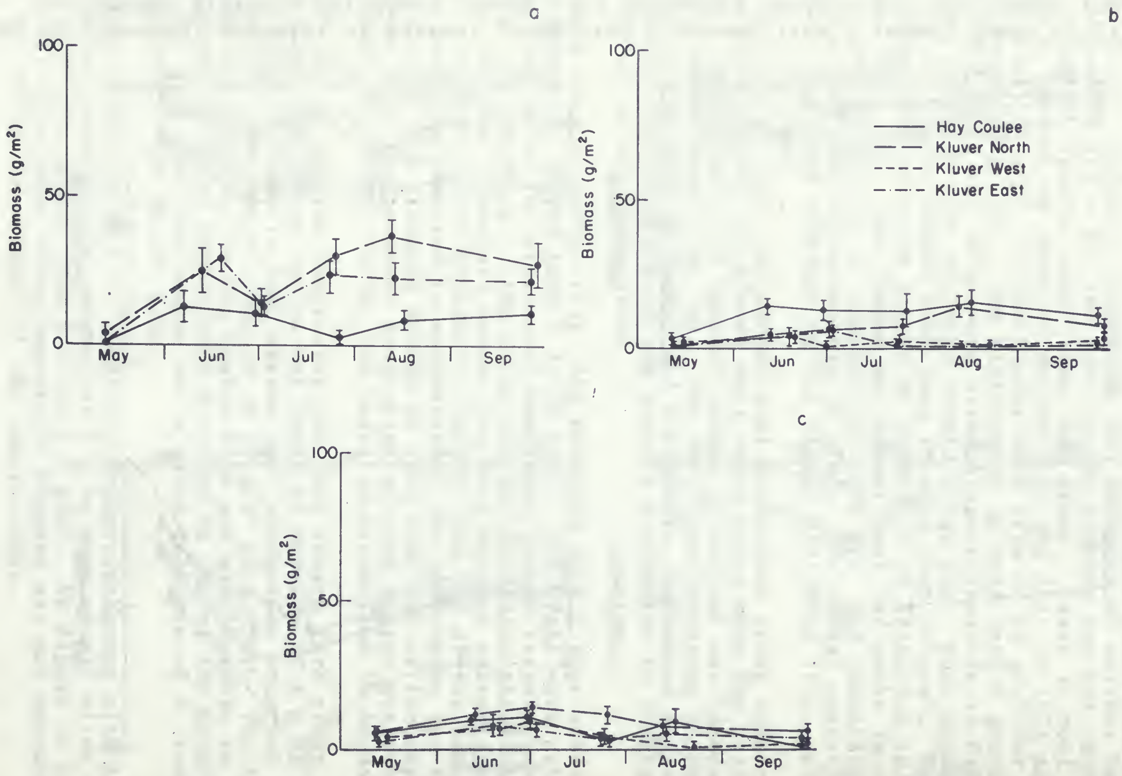

Fig. 3. Seasonal dynamics of current production (current live + recent dead) of (a) half-shrubs, (b) warm season grasses, and (c) cool season forbs for the four Colstrip sites in 1974.

samples were very close to the peak biomass of the majority of the species. Peak current season production of the various groups was similar to the Colstrip sites except that there were essentially no warm season grasses. Peak production for cool season grasses and cool season forbs was 73 and 21 g/m², respectively. Half-shrub production was 20 g/m² and warm season forbs contributed 2 g/m² to total production.

Litter Biomass

Estimates of litter standing crop ranged from less than 150 g/m² to more than 200 g/m² and exhibited few if any definite trends in seasonal dynamics (Fig. 4). It appears that a net decline may have occurred over the course of the growing season. Consistent differences in litter standing crop do not exist among the Colstrip sites. The Ash Creek site appears to have lower amounts of litter than the Colstrip sites, at least during early June (153 g/m²) and early July (154 g/m²).

Belowground Biomass

Since sampling was not initiated until 15 May, we gained an incomplete picture of the intraseasonal dynamics of root biomass in 1974. Although there were no dramatic changes in root biomass during the sampling period on the Colstrip sites, a net decline in root mass took place between May and September (Fig. 5). Since the sampling method used to determine root biomass does not partition the material into live and dead components, it is impossible to ascertain from these data the dynamics of each of these components (live and dead). Other studies (3, 9) have shown that there is often a decrease in root biomass very early in the season that is succeeded by an increase following more complete development of the photosynthetic tissue. We suspect that such a decrease occurred well before our first sampling date.

The vertical distribution of roots was examined on one date for each of the five study sites. Differences in the vertical distribution of root biomass did not exist among the Colstrip sites. However, the Ash Creek site had a higher proportion of the total root biomass in the 0-10 cm level than the Colstrip sites (Fig. 6). This may be the result of differences in botanical composition, soil characteristics, or grazing history. Differences between the areas do not exist when the 0-30 cm level proportions of total root biomass are compared for the Colstrip and Ash Creek areas (77% and 79%, respectively).

Net Primary Production

Many methods have been used to estimate net aerial production from harvest data (12) although it is difficult to determine a "best" method. We have selected two methods: The first involves summing the peak amounts of current production (live + recent dead) for each functional group, and the second method entails summing the peak production estimates of each species. The first method has the advantage of smaller standard errors associated with the estimates of current growth. The second method considers that the phenology of each species is distinct and that peak growth within the groups is not necessarily

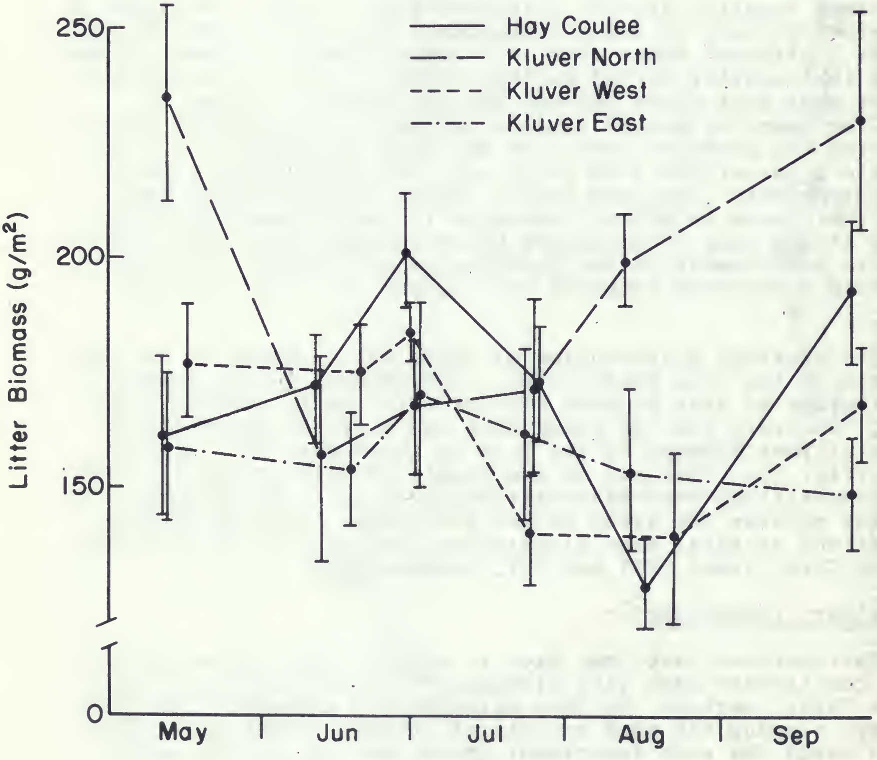

Fig. 4. Seasonal dynamics of litter biomass for the four Colstrip sites in 1974.

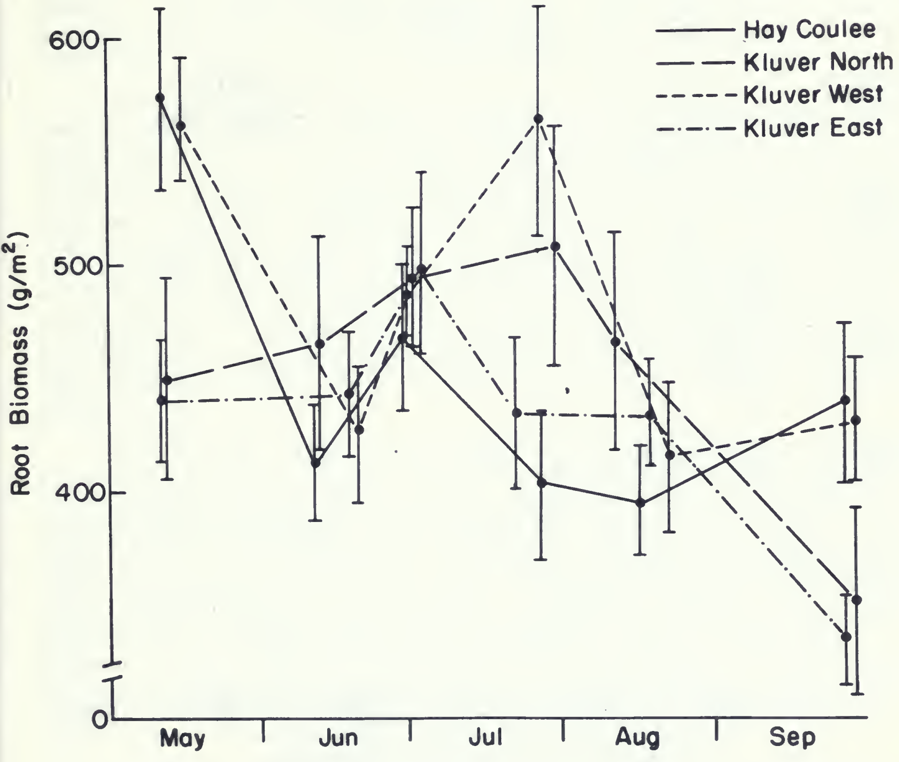

Fig. 5. Seasonal dynamics of root biomass for the four Colstrip sites in 1974.

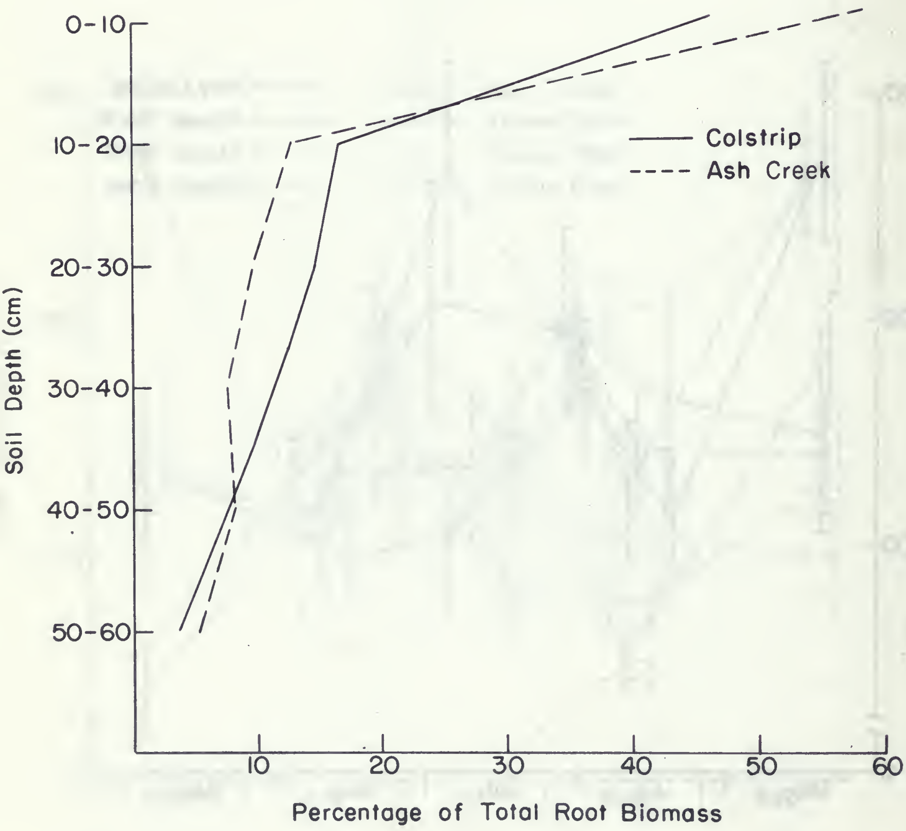

Fig. 6. Comparison of the vertical distribution of root biomass between the mean of the four Colstrip sites and the Ash Creek site.

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attained at the same time.

Net aerial primary production for the five sites estimated by the first method ranged from 106 to 123 g/m^2 (Fig. 7). Estimates by the second method were higher as expected and ranged from 117 to 149 g/m^2 (Table 2).

Dahlman and Kucera (2) have shown that minimal estimates of the portion of net primary production translocated belowground can be made by examining belowground biomass dynamics and considering significant increases within the season as belowground primary production. Only one site (Kluver West) exhibited a significant increase (about 120 g/m^2).

DISCUSSION

The suitability of the study sites to meet our objectives of assessing the effects of atmospheric emissions from a large coal-burning electrical power plant on the vegetation of the northern mixed prairie requires that they meet two general criteria. The first is that the sites are "typical" northern mixed prairie sites enabling us to generalize our results to a larger area; the second is that the sites are homogeneous enough so that treatment effects can be separated from site differences.

From the point of view of vegetation structure our sites appear to be "typical" of many northern mixed prairie sites. Weaver and Clements (17) list the most widespread dominants of the mixed prairie as *Stipa comata*, *Sporobolus cryptandrus*, *Agropyron smithii*, *Koeleria cristata*, *Bouteloua gracilis*, and *Buchloe dactyloides*. *Agropyron smithii* is one of the dominants on all of our sites, sharing dominance with *Bouteloua gracilis* on the Hay Coulee site, *Stipa comata* on Kluver West, *Stipa comata* and *Artemisia frigida* on both the Kluver North and Kluver East sites, and *Koeleria cristata* on the Ash Creek site. Coupland (1) described the distribution of A. *smithii* as extending from southern Canada to Texas, and Weaver and Albertson (16) described A. *smithii* as one of four dominant grasses that occur throughout the extent of the mixed prairie.

Singh et al. (12) investigated the range of values obtained by 31 methods of calculating aboveground net primary production in grasslands from harvest data. They report 64 estimates of aboveground production for a northern mixed prairie site in North Dakota and 186 estimates for a similar site in South Dakota. The range of estimates for both grazed and ungrazed grasslands in North Dakota was 119 to 471 g/m^2. Estimates by the two techniques that we used in this paper were 351 g/m^2 by summing peak current production by species and 208 by summing peaks of functional groups for the ungrazed area and 302 and 206 g/m^2 for the grazed area. In comparison our sites are less productive. The difference in production was mainly attributable to the greater productivity of *Stipa comata* on the North Dakota site.

Aerial net primary productivity estimates for the South Dakota site over 3 years of measurement ranged from 173 to 973 g/m^2 for the ungrazed treatment and 129 to 619 g/m^2 for the grazed (12). Estimates for summing species peaks ranged from 248 to 365 g/m^2 for the ungrazed grassland and 163 to 220 g/m^2 for the grazed. Summing peak production by groups yielded a range of

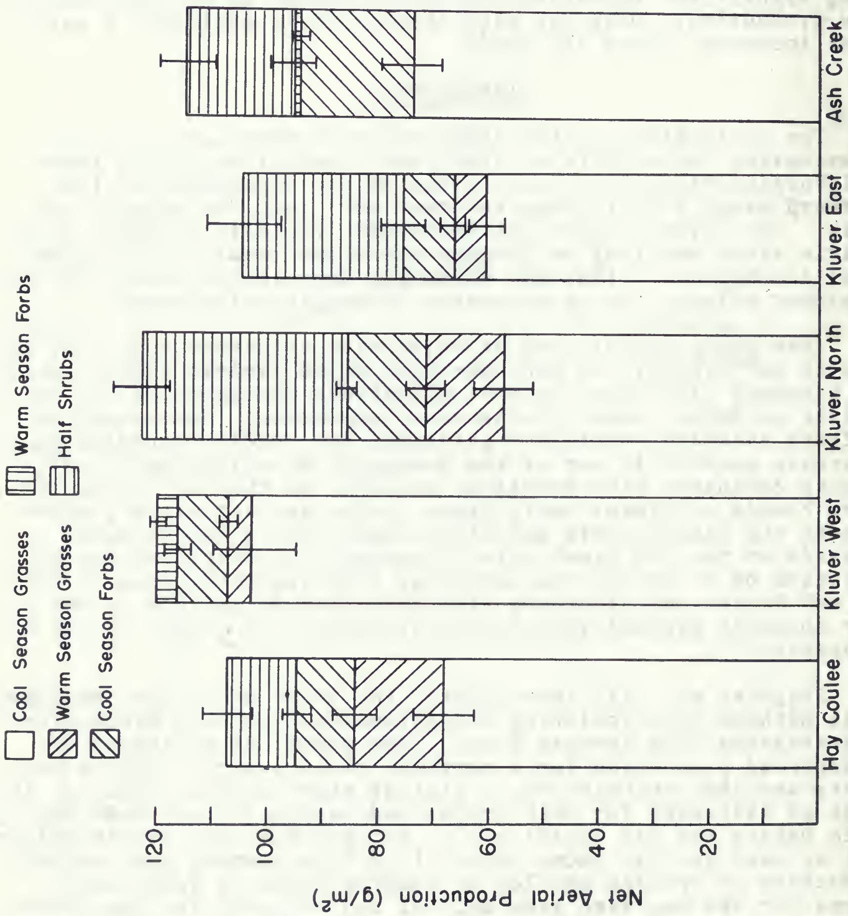

Fig. 7. Functional group composition of total net aerial production and standard errors for the five mixed prairie sites in southeastern Montana in 1974.

Table 2. Peak current season production (g/m^2), standard error of estimate, and the date (day/mo) when the peak occurred, by species, for five mixed prairie sites in southeastern Montana in 1974.

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
COOL SEASON GRASSES															
Agropyron cristatum										12.00	3.00	2/7			
Agropyron smithii	43.00	3.00	11/6	17.00	5.00	30/6	24.00	6.00	25/7	39.00	5.00	18/6	23.00	4.80	10/7
Bromus japonicus	23.00	4.00	29/6	31.00	3.00	20/6	19.00	5.00	12/6	9.00	2.00	2/7	14.00	6.50	10/7
Calamagrostis montanensis													9.00	2.30	10/7
Carex eleocharis													0.40	0.32	10/7
Carex filifolia				5.00	1.00	15/5	4.00	3.00	1/7						
Carex pennsylvanica													0.43	1.20	3/6
Festuca octoflora	0.16	0.06	29/6	0.18	0.02	24/7	0.04	0.03	12/6	0.02	0.02	2/7	0.21	0.24	3/6
Koeleria cristata	5.00	3.00	29/6	0.53	0.45	24/7	1.00	0.67	1/7	0.04	0.03	12/5	25.00	2.80	3/6
Poa secunda	2.00	0.50	11/5	0.77	0.33	15/5	1.00	0.39	12/5	0.84	0.41	12/5	9.00	2.00	3/6
Stipa comata	0.14	0.14	11/5	57.00	5.00	30/6	32.00	8.00	28/9	7.00	3.00	2/7	0.58	0.68	10/7
WARM SEASON GRASSES															
Aristida longiseta				0.04	0.04	22/8	3.00	2.00	12/8						
Bouteloua gracilis	16.00	4.00	16/8	4.00	2.00	20/6	11.00	4.00	12/8	6.00	3.00	2/7			
Schedonnardus paniculatus	0.02	0.02	29/6							0.48	0.46	12/5			
Sporobolus cryptandrus	0.02	0.02	26/9												
WARM SEASON FORBS															
Antennaria neglecta	0.06	0.02	11/5	0.10	0.03	15/5	0.02	0.02	12/6				0.30	0.47	3/6
Arnica fulgens													0.12	0.46	3/6
Circium undulatum										0.02	0.02	2/7			
Conyza canadensis							0.06	0.04	12/8				0.32	0.25	10/7
Erigeron spp.													0.71	1.00	10/7
Gaura coccinea	0.02	0.02	11/5	0.02	0.02	30/6	0.08	0.05	25/7	0.04	0.04	23/7	0.31	0.29	10/7

(Continued next page)

Table 2. Continued.

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
Grindelia squarrosa							0.47	0.47	1/7						
Lygodesmia juncea				1.00	0.82	30/6									
Orthocarpus lutea													0.72	0.49	10/7
Polygala alba	0.08	0.06	16/8							0.04	0.04	26/9			
Psoralea argophylla				2.00	1.00	30/6							2.00	1.00	10/7
Psoralea tenuiflora				0.08	0.05	24/7	0.55	0.53	12/6	0.04	0.04	23/7	2.00	2.00	10/7
Ratibida columnifera													0.008	0.008	3/6
Senecio spp.							0.27	0.27	1/7						
Solidago rigida													0.13	0.27	10/7
COOL SEASON FORBS															
Achillea millefolium	0.02	0.02	11/5										15.00	5.00	10/7
Androsace occidentalis	0.06	0.02	11/6	0.06	0.02	15/5	0.04	0.02	12/6				0.08	0.02	10/7
Astragalus spp.				0.04	0.04	24/7	0.15	0.13	12/5				0.06	0.15	10/7
Cymopterus acaulis	0.02	0.02	11/5				0.02	0.02	12/5				0.001	0.005	10/7
Descurainia spp.				0.02	0.02	28/9									
Draba reptans				0.12	0.03	15/5									
Erysimum asperum				1.00	1.00	30/6	1.00	0.91	1/7	0.63	0.58	2/7			
Hedeoma hispida	0.50	0.26	29/6	0.28	0.06	30/6	0.20	0.07	1/7	0.10	0.03	23/7	0.12	0.03	10/7
Lappula redowskii													0.07	0.29	3/6
Lepidium densiflorum	0.12	0.03	11/6	0.08	0.03	20/6	0.16	0.06	1/7	0.02	0.02	2/7			
Leucocrinum montanum				0.77	0.35	15/5	0.47	0.16	12/5	0.10	0.10	18/6	0.07	0.07	3/6
Lithospermum incisum													0.22	0.24	3/6
Linum rigidum	0.42	0.29	16/8												
Lomatium orientale	0.06	0.02	11/5	0.04	0.02	15/5	0.02	0.02	12/5				0.02	0.02	3/6
Penstemon spp.							0.02	0.02	28/9						
Plantago patagonia	0.36	0.03	29/6	3.00	1.00	30/6	0.28	0.06	1/7	0.16	0.06	2/7	0.62	0.50	3/6
Phlox hoodii	6.00	5.00	16/8	2.00	2.00	15/5				3.00	3.00	13/8	3.00	3.00	3/6
Selaginella densa													0.003	0.01	10/7
Sphaeralcea coccinea	0.04	0.02	11/5	1.04	0.93	20/6	1.00	1.00	25/7				0.46	0.26	3/6

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Table 2. Continued.

Species	Hay Coulee			Kluver West			Kluver North			Kluver East			Ash Creek		
	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date	Mean	Std. Error	Date
Taraxicum officinale	3.00	0.85	11/5	0.41	0.28	20/6	0.17	0.13	12/5	0.24	0.07	2/7	3.00	1.00	3/6
Tragapogon dubius	9.00	2.00	29/6	5.00	0.59	20/6	12.00	1.00	1/7	6.00	1.00	2/7	2.00	1.00	10/7
Vicia americana													0.002	0.01	10/7
Zygadenus elegans													0.07	0.09	3/6
Misc.	0.10	0.03	11/5	0.17	0.17	30/6	0.02	0.02	12/5				0.42	0.47	3/6
HALF-SHRUBS															
Artemisia cana	0.04	0.04	26/7										0.25	0.41	3/6
Artemisia dracunculoides							0.02	0.02	1/7	0.04	0.04	23/7	0.01	0.05	10/7
Artemisia frigida	11.00	4.00	29/6	0.27	0.23	30/6	37.00	5.00	12/8	29.00	6.00	18/6	12.00	4.00	10/7
Artemisia ludoviciana													2.00	2.00	10/7
Artemisia tridentata	0.08	0.06	16/8												
Eurotia lanata	2.00	2.00	11/5												
Gutierrezia sarothrae	0.45	0.45	26/9										5.00	3.00	10/7
Rosa arkansana													0.001	0.005	10/7
OTHERS															
Parmelia chlorochroa				0.02	0.02	15/5	0.02	0.02	12/6						
Mammilaria spp.				0.08	0.06	24/7	0.04	0.04	25/7						
Opuntia polyacantha	0.04	0.02	29/6				0.08	0.06	25/7	0.57	0.57	18/6			
Opuntia fragilis	0.04	0.04	26/7	0.04	0.03	30/6	0.08	0.06	25/7	0.04	0.04	23/7			
Echinocereus viridiflorus				0.41	0.29	20/6									
TOTAL NET PRODUCTION		123			134			149			114			133	

Table 3. Analysis of variance for the response of aerial net primary production to the four Colstrip sites and five primary producer groups.

Source	d.f.	Sum of Squares	Mean Square	F	P
Sites	3	92.26	31.09	0.46	0.713
Groups	4	22749.10	5687.28	84.52	<0.0001
Site × Group	12	7649.99	637.50	9.47	<0.0001
Error	20	1345.83	67.29		

Table 4. Analysis of variance for the response of aerial net primary production to the Kluver North, Kluver East and Hay Coulee sites and five primary producer groups.

Source	d.f.	Sum of Squares	Mean Square	F	P
Sites	2	74.81	37.40	0.43	0.658
Groups	4	13864.85	3466.21	40.15	<0.0001
Site × Group	8	776.16	97.02	1.12	0.404
Error	15	1295.08	86.34		

193 to 235 g/m^2 for the ungrazed and 139 to 249 g/m^2 for the grazed treatment. Again the Montana sites were less productive than the South Dakota grassland, but the estimates overlap at the lower end of the range. Rainfall at the sites reported by Singh et al. (12) was above average during the years that harvest data were reported. Precipitation data from Colstrip, Montana, approximately 15 km from the sites indicate that April and May of 1974 were wetter than normal, but June, the month in which cool season grass peak production was measured, was 57 mm below average.

Analysis of variance of aerial net primary production by species groups (Table 3) indicates that there were no differences in average net primary production among the Colstrip sites in 1974, but that there was a significant ($P < 0.0001$) site × functional group interaction. Evaluation of the site × group interaction revealed that the significant response was attributable to the data from the Kluver West site. The almost complete lack of half-shrubs on this site (Fig. 3) was compensated for by a 40% increase in the net production of cool season grasses (Fig. 2). Repeating the analysis without the Kluver West data (Table 4) resulted in a nonsignificant site × group interaction indicating that the contribution of species groups to net primary production was not different among the three remaining sites. On this basis we can conclude that three of our sites are similar enough to separate any effects of air pollution from site differences. These results do not mean that the Kluver West site will be of no use to our study because many of our future analyses will be concerned with the changes in individual sites as a function of time of exposure to power plant emissions. The dominant species on Kluver West site *Stipa comata* is well represented in other mixed prairie communities and the fact that we have two community types represented in our study may increase the generality of our results.

ACKNOWLEDGMENTS

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Fort Union Coal Field Symposium

THE EFFECTS OF COAL-FIRED POWER PLANT EMISSIONS ON VERTEBRATE ANIMALS

Robert A. Lewis and Martin L. Morton*

INTRODUCTION

This investigation is one component of the Environmental Protection Agency's Montana Coal-Fired Power Plant Project.

Major objectives of this project element are to:

1. Measure and predict change in population structure and/or dynamics of selected species of birds and mammals as a function of air pollution, endogenous and exogenous cycles, and other environmental information including relevant biotic interactions and physical factors.

2. Evaluate physical and biotic factors that influence the dynamic-structural processes under investigation.

3. Identify, if possible, specific pollution effects on animal populations or systems.

4. Identify physiologic and population functions that contribute to the regulation of selected populations and to evaluate the mechanisms whereby such regulation is effected, so that we may better interpret the causes of changes that occur. We may thus increase our understanding of pollution-related effects and the confidence in our output.

5. Evaluate certain physiological, biochemical, and behavioral functions that we think have a potential for sensitive assay of pollution challenge. We thus hope to be able to identify low levels of pollution stress before serious or irreversible effects occur.

Furthermore, in order to address the overall goals of the Montana Coal-Fired Power Plant Project (9) we are attempting to identify: (a) those populations (or taxa) of birds and mammals that are most sensitive to air pollution in the study area; (b) those species, systems, and functions that may serve as specific, "noise-free" indicators of pollution (e.g., physiologic control systems); (c) population components that may serve as a measure of impact in the sense that they themselves are ecosystem resources or are coupled to ecosystem resources. We shall then attempt to relate, if possible, functions of types (b) and (c) to evolve extrapolative or predictive models. We hope also to determine the extent of pollution-related effects on small mammal and bird populations in the study area, and if possible, to distinguish between direct and indirect air pollution effects and effects of other human activities that might tend to confound our results (e.g., effects of coal-mining, water use, increased human population density, use of herbicides and pesticides, etc.).

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Animal response to air pollution challenge varies seasonally; as a function of resource availability; as a function of sex and age, and in response to secondary stress from diverse sources (e.g., high population density, disease, competing or interacting populations, other pollutants).

Our work is thus strongly dependent upon baseline evaluation of annual cycle and life cycle phenomena and the mechanisms that regulate such functions. We hope that appropriate analysis of the temporospatial relationships of observed changes in animal function can be related to those of other ecosystem components (e.g., plant community structure) so that predictive relationships can be established.

Based on our interpretation of the literature of environmental physiology, toxicology, and to a lesser extent on health related studies of air pollution effects, we anticipate that power plant emissions may have effects at nearly all levels of animal organization. We do not know, however, the "threshold" exposure rates that might be expected to produce various biological effects. This naiveté on our part (coupled with the low pollution levels that are anticipated from the facility under investigation) has strongly conditioned our approach. This investigation is thus based more upon the application of what we believe to be sound biological principles than upon the application of the results of air pollution science or of health effects studies.

The very limited literature (which we shall review in a later publication) that deals with the effects, on animals, of low levels of pollutants from coal-fired power plants is, nevertheless, encouraging and suggests that:

1. Some birds may be especially susceptible to gaseous emissions from coal fired power plants.

2. Dispersion of animals about a stationary source, in response to air pollution, may change within a very short time.

3. At low levels of pollution, transient effects are likely to occur.

4. Birds are especially sensitive during the breeding season; the longer the breeding season, the heavier the damage sustained.

5. Changes in organ weights occur in response to ambient pollution levels that are well below present standards. For example, in one study, increased weights of liver, kidneys, spleen and adrenal glands occurred (starting at 30 days) in white rats exposed to polluted air containing SO_2, SO_3 mist, and airborne dusts at very low concentrations (i.e., 0.034-0.077 ppm, 6.7-9.5 $\mu g/m^3$ and 0.076-0.128 mg/m^3, respectively). Clean room controls did not exhibit these changes. The increase in liver weight was transient.

6. Protein metabolism is altered at very low pollution levels in some animals; a negative nitrogen balance may be induced. For example, in one study, flue gas (mixed with air) with an SO_2 concentration of 1 mg/m^3, produced a decrease in liver protein of guinea pigs.

7. Lung damage occurs in some birds at low pollutant levels. This is apparently due in part to the poor filtering ability of the nasal passage. Doves (Japan) in polluted areas sustain far greater lung damage than humans.

8. Chronic levels of NO_x impair lipid metabolism of guinea pigs and may exert an arteriosclerotic effect.

9. Acetylcholinesterase (blood and liver) and ascorbic acid (liver, lung) concentrations may be sensitive measures of pollution.

10. Species of vertebrates vary widely in their responses and sensitivities to air pollution. The standard laboratory animals maintained under good conditions of housing and nutrition are possibly much less sensitive to pollutant stress than some of the more sensitive feral animals.

Needless to say, the scope of our work is such that not all components can receive the same intensity of effort. These are thus listed below in order of decreasing priority:

I. Reproductive and developmental biology.

II. Measures of condition, physiologic stress, homeostasis, and adaption.

III. Population biology.

IV. Histological cycles of organ-systems of potential or probable concern.

V. Experiments.

Briefly, the reproductive and developmental portion of the study focuses on the description of the annual reproductive cycles of a small set of indigenous species together with the growth and development of young to include information on bioenergetics, productivity, and the regulation of reproductive processes and of postnuptial molt (birds). The species of primary concern are the Mourning Dove (*Zenaidura macroura*), Western Meadowlark (*Sturnella neglecta*), Lark Bunting (*Calamospiza melanocorys*), Vesper Sparrow (*Pooecetes grammacus*), Lark Sparrow (*Chondestes grammacus*), Deer Mouse (*Peromyscus maniculatus*), and Prairie Vole (*Microtus ochrogaster*). The second or physiological component treats a number of types of functions, notably those that reflect condition and vigor of the animals and their responses to stress. The third portion of the investigation deals with population processes and at least some of the mechanisms that effect population adjustments (e.g., fecundity, mobility). The fourth phase of this investigation, the evaluation of histological cycles, is designed to support the other components. In addition, since it is impossible to fully anticipate which tissues or organ systems may be most affected by chronic pollution stress, we are establishing a tissue bank of the major organs that might be expected to show involvement. Laboratory experiments will be conducted to test field-generated or model-generated hypotheses and/or to identify specific pollution effects suggested by observed field responses.

REPRODUCTION AND DEVELOPMENT

The reproduction component of this investigation overlaps and supports the population-dynamic component. In addition, the reproductive and life cycles are of special and independent concern. We feel that significant impairment of animals at the population level will be reflected in altered reproductive performance and/or developmental patterns.

The reproductive cycle of North Temperate Zone vertebrates is, in general, the best characterized of the annual subcycles. Furthermore, regulatory mechanisms are fairly well known (4, 10, 14). We are thus in an excellent position to assess the effects of air pollution on reproductive functions.

Lowered growth rates to the time of nest departure of altricial birds and rodents, by whatever agency (e.g. air pollution), would increase the period of time that the young remain in the nest and their period of dependence upon parental care. They would thus be exposed to relatively high predation rates for a longer than normal period and also both parents and young might suffer a competitive disadvantage during and immediately following departure from the nest (see Figure 5 and accompanying text).

We expect that immature mammals and birds may be especially sensitive to pollution effects. Furthermore, rates of growth and development can be easily related to several functions that are being described by other components of the Montana Coal-Fired Power Plant Project (9). Our study of development is restricted to a few indigenous bird and mammal species and treats the following:

1. Growth and maturation rates and phenology.
2. Biometry of growth.
3. Growth and development in relation to:
    a. Plant community structure and change.
    b. Climate
    c. Nutritional environment
    d. Pollution concentrations
    e. Molt progress and intensity.
4. Caloric and nitrogen balance as indicators of condition and ability to obtain and utilize nutritional resources.
5. Covariance of the above functions with physical environmental factors and air pollution gradients.

CONDITION, STRESS, ADAPTATION AND DISEASE

This phase of the vertebrate research deals with a number of functions and systems that may be expected to reflect the health and condition of the animals under investigation. Of particular interest are the following:

1. Bioenergetics (to include body weights, body composition (water, lipid, etc), growth rates) and nutritional biology.

2. Adrenocortical system and responses to stress (e.g., general adaptation syndrome of mammals).

3. Immunobiologic responses (e.g., blood and reticuloendothelial system responses).

4. Disease and histopathology.

5. Behavior patterns (e.g., mobility, territorial behavior, niche utilization, etc.).

The measures of condition that we employ are regulated functions. That is, they tend to be maintained within relatively narrow limits at any given stage of the annual cycle. Such functions are, of course, frequently age and sex-dependent. We may thus expect that some of these will provide relatively stable frames of reference against which environmental impacts can be measured.

We are employing standard biometric methods and whole carcass and organ analysis of selected species of rodents and birds to evaluate compositional and biometric changes as a function of age, sex, season and physiologic state in relation to the physical and biotic environment. The main purpose of this type of analysis is to better assess condition, vigor, nutritional state, and net energy and protein balance as a function of air quality and other environmental parameters.

Major body and organ components that are measured and evaluated include live wet weight, lean wet weight, lean dry weight, lipids, allometry of feather growth (birds) and of related functions, stomach and crop (birds) contents and weights, caloric density of the diet, parasite burdens (e.g., of intestinal tract and perhaps of blood), and dietary and tissue protein levels.

POPULATION BIOLOGY

In this component of the study we are attempting to assess changes in population size and structure of several indigenous species as a function of mortality recruitment rates and life cycle functions. We would like, ultimately, to be able to predict changes in any or all of these as a function of pollution intensity. We would like, also, to determine the growth potential of the populations of concern. That is, we would like to establish the capacity of the populations of interest to tolerate (or to recover from) challenge (especially from air pollutants) or perturbations that alter life functions and thereby tend to reduce the population or alter its composition.

Because of the relatively low signal-to-noise ratio in many population dynamic functions, we may expect the short-term chronic effects of air pollutants on population parameters to be small relative to natural and/or random variation. Thus appropriate sensitive analysis requires: (a) a pollution gradient across study sites (mammals and perhaps birds); (b) employment of reference sites that will allow us to estimate variations both between and within years (birds and mammals); (c) investigation and characterization of responses that may be pollution specific (birds and mammals); (d) investigation of associated functions that may represent deviations from the normal pattern or the phase-shifting or uncoupling of normally coupled phenomena; (e) evaluation of changes in population structure rooted in a study of annual cycle and life cycle components (e.g. time-based changes in sex and age structure; breeding success, etc.).

Assessments of life table functions will be made in order to help us to determine the mechanisms of population changes that may occur. The field methods employed in the acquisition of such information have been adapted from published methods. The functions that form the basic life equation of small birds and mammals are:

1. Number of eggs laid per clutch or young formed per litter.
2. The frequency at which clutches are laid or young are born.
3. Survivorship (eggs, young) to the age of first breeding.
4. Survivorship of adults during their reproductive lifetime.
5. Age of sexual maturity.

These kinds of data will be employed in models to help us (in combination with behavioral and physiological data) to evaluate population sensitivity to selected pollutants or to generate hypotheses to be tested by laboratory experiments.

In addition to intensive studies of a few abundant indigenous species at fixed study sites we are conducting infrequent surveys using standard census techniques (3, 13) to assess changes in diversity and relative abundance of vertebrates in the study area.

HISTOLOGICAL CYCLES OF ORGAN-SYSTEMS OF POTENTIAL OR PROBABLE CONCERN

A system of tissue banking has been initiated whereby several tissues and organs of the animals collected in the field are fixed and routinely embedded. As pollution-sensitive species and tissues are identified, appropriate specimens will be stained and examined histologically. Organ-systems of probable importance include the respiratory system, blood, adrenocortical system, reticuloendothelial system, liver and the reproductive system. Elements of these systems will definitely come under study.

PROGRESS TO DATE

Collections of small mammals and birds employing standard mark and release methods, were initiated at five stations situated from 8-24 km from the plant. In addition, bird specimens are collected via shotgun at various locations both within the study area (but never closer than 1 mile from the sites where live animals are studied) and in reference areas in Rosebud and Powder River counties.

Mammals are collected by means of two trapping systems, one for the collection of specimens for necropsy and another for mark-release data. Live traps are used in both cases.

Collections

Rodents are livetrapped one day per week and returned to the laboratory for processing. Body weight and length measurements (body, ear, hindfoot and tail) are taken. Following ether anaesthesia, blood is taken from the orbital sinus in a capillary tube. From this is determined hematocrit (via centrifugation) and plasma protein concentration (via diffraction meter). Heart, lungs, kidneys, adrenals, spleen, liver, gonads and oviducts are preserved in Bouins, weighed after one week, and transferred to 70% ethanol for subsequent embedding. Carcasses are saved frozen for analysis of components. More than 200 small mammal specimens have been collected thus far. Femurs from 80 animals have been frozen and mailed to C. Gordon (University of Montana) for determination of fluoride content.

Mark-release

Grids with outside dimensions of 150 m x 150 m have been established at five locations. Trapping stations within each grid are 15 m apart; thus there are 121 stations/grid. Two traps are set at each station; a total of 242 traps/grid. The grids are trapped in regular rotation following three or four nights of prebaiting with rolled oats.

All rodents trapped are toe-clipped according to a standard numerical scheme, weighted, measured, and examined for external signs of sexual activity and other factors such as ectoparasites and pelage changes. Releases are made at the station of capture. At this time 313 individuals have been marked and released. A total of 305 recaptures have occurred. The species captured in descending order of frequency, are *Peromyscus maniculatus*, *Microtus ochrogaster*, *Perognathus fasciatus*, *Reithrodontomys megalotis*, and *Onychomys leucogaster*. In addition we have caught a few specimens of *Peromyscus leucopus*, *Citellus tridecemlineatus* and *Sylvilagus audubonii*.

Trapping results -- Small Mammals

The percentage of each species comprising our catch on the five grids vary seasonally (Figure 1). Numerous interacting factors account for this variation and these undoubtedly vary among species. In the case of *Onychomys leucogaster*, for example, none were captured until the grasshopper population crashed in August. Beyond October neither *O. leucogaster* nor *Perognathus* *fasciatus* were captured and both species are presumed to have entered hibernation. An interesting aspect of trappability in *P. fasciatus* is that nearly all specimens were taken in two nights, when traps were left open during rainstorms.

The species most consistently captured was *Peromyscus maniculatus*. It comprised from 52 to 79 percent of the total catch during every month. *Microtus ochrogaster* also made up a fairly consistent portion of the catch, 13 to 33%, although they were not taken at every trapping session as was the case for *P. maniculatus*.

Most studies show little overlap in the distribution of *Peromyscus* and *microtus*. Recently, however, locally sympatric populations have been found in a wet praire community (11). Our analysis of niche dimensions involved in the ecological separation of *Peromyscus* and *microtus* in relatively arid shortgrass prairie will be important for comparative purposes and for testing the applicability of models such as those that deal with utilization of space by small mammals (2, 12). Our routine trapping of grids is yielding demographic information particularly on *P. maniculatus*. The proportion of adults in our samples decreased in autumn (Figure 2). Reproduction ceased in December so we expect the proportion of adults to increase through the winter as young animals continue to attain adult size and pelage. Males formed a remarkedly constant proportion of the catch, about 60% in all months (Figure 2). The sex ratio observed in 621 captures of *P. maniculatus* was 1.52:1. This is an unbalanced sex ratio that deviates significantly from 1:1 ($P < 0.005$) according to a chi-square test.

Body weights of *P. maniculatus* showed considerable seasonal variation (Figure 3). This variability is expected in immatures because of growth and constant recruitment and in adult females because of varying reproductive status. Adult males show much less variation. However, a slight but regular increase in mean body weight occurred from July through January. Our analysis of whole body composition should reveal the basis for this increase (e.g., pelage, growth or fattening).

A few examples of our baseline results on growth, condition, and nutrition are summarized in Figures 4, 5 and 6. These data illustrate the pronounced seasonal and diurnal changes that occur. These types of variation are pervasive in living systems and are of concern in the study of pollution effects for at least two major reasons: (a) both experimental design and field sampling protocols must be structured to control or describe these kinds of variations, and (b) the sensitivities and exposure rates of animals to air pollutants and to other sources of stress vary both as a function of the time of day (1, 6, 7, 8) and time of year (5, 15).

During the hot, sunny days of summer, Mourning Dove *Zenaidura macroura*, feed intensively during the first few daylight hours and again late in the day. This cycle of activity is reflected in the amount of food in the crop, a storage organ (Figure 4). Clearly, the activity patterns and feeding rates of these birds may influence both the rate of exposure and susceptibility to air pollutants. Consequently pollution effects may be a function of both the magnitude of and time of occurrence of peak concentrations of the pollutants. Interestingly, daily maxima in air pollution concentration from coal-burning processes frequently show strong diurnal cycles.

Briefly, the seasonal pattern of growth and development of male and female Western Meadowlarks, *Sturnella neglecta* (Figure 5, 6), that we observed in Rosebud and Powder River countries in 1974, differed substantially. Our data suggest that females might be more susceptible to environmental stress than males. They may thus be a promising system to evaluate. Note, for example, that body weight both as a function of season (Figure 5) and developmental (i.e., molt) status (Figure 6) differs in males and females. The differences in body weight appear to reflect differences in nutritional or energetic balance (Lewis and Morton, unpublished).

Note also that no females were collected in late September (Figure 5). The disappearance of this group from the sample population is of considerable interest and could be due to a sampling bias, a relatively high mortality rate or, less likely, earlier migration out of the study area.

A standard roadside census of birds, to be conducted from April through September at biweekly intervals, was instituted in 1974. This census is patterned after that of the North American Breeding Bird Survey (13). The 50 census points are located from 0.8 to 24 km from the plant. This census should provide us with fairly sensitive data on significant changes in species diversity; changes in relative and absolute abundance; changes in dispersion in relation to the coal-fired power plant at Colstrip; and supplemental information on sex and age ratios, productivity, and the annual calendar of some species. Based upon the combined results of netting and censusing, the most abundant and widely-distributed grassland bird species in the study area are the Western Meadowlark, Vesper Sparrow and Lark Sparrow.

Birds were trapped by the use of four 12 meter mist nets that are set at dawn and usually operated until noon. Following capture, they were banded with U. S. Fish and Wildlife Service numbered bands, weighed, examined for sex, breeding condition (degree of development of the brood patch; cloacal protuberance) molt, ectoparasites, and then released at the site of capture. A total of 318 birds, representing 33 species were banded and released. Of these, only six percent (two species) occurred at all of the netting stations and only 30 percent were present at more than one site.

More than 300 birds have been collected by shooting. These are frozen and transmitted to the animal physiology laboratory in Corvallis. Five species are specifically sought. These are the Vesper Sparrow, Lark Sparrow, Western Meadowlark, Mourning Dove, and Lark Bunting.

ACKNOWLEDGEMENTS

Technical assistance for this study is provided by a large number of people. We would like especially to thank Susan Jones and Larry Doe for major and continuing contributions.

Figure 1. Seasonal changes in species composition, of rodents captured on grids near Colstrip, Montana, in terms of trapping frequency. Note that *Onychomys* and *Perognathus* are hibernators.

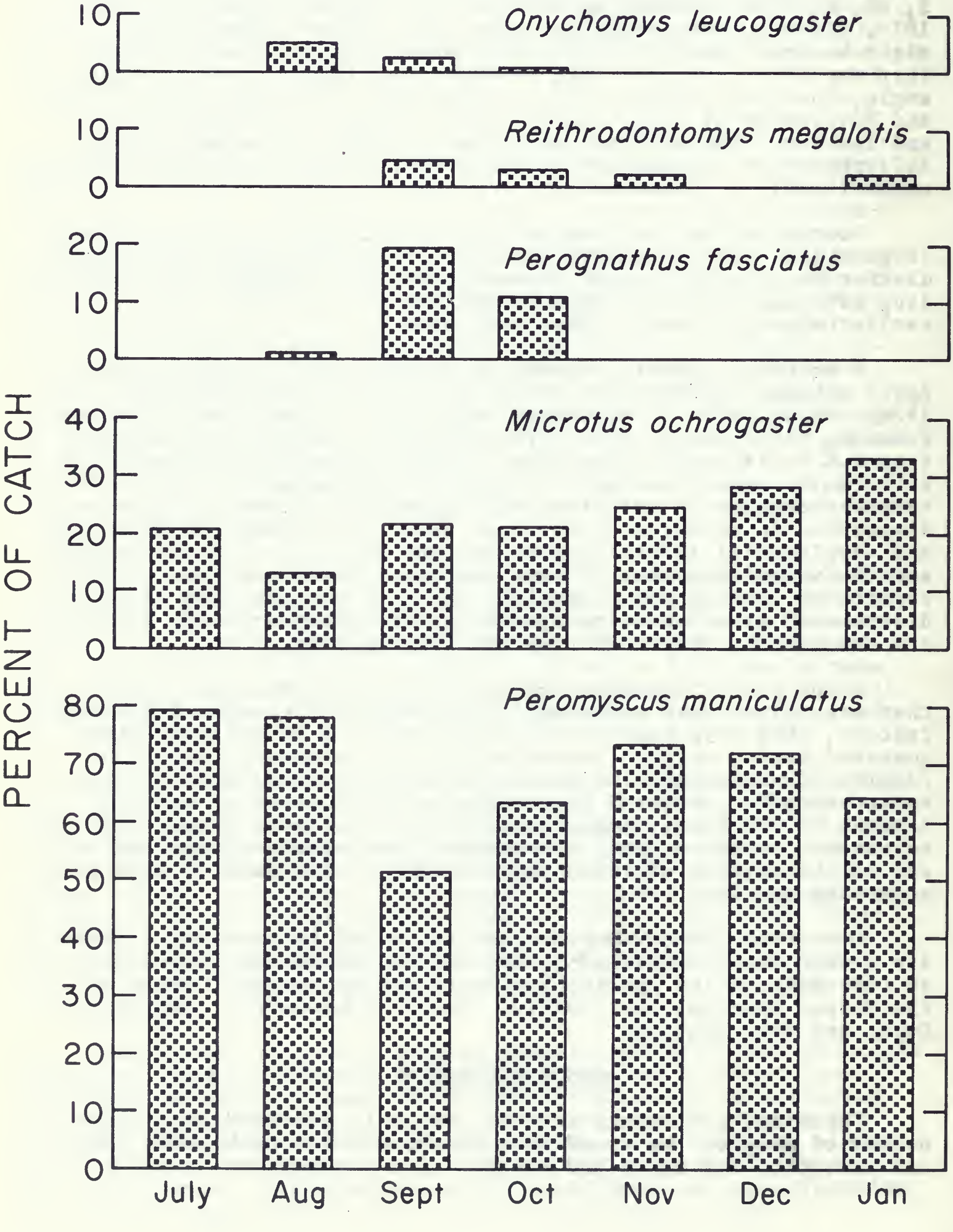


Figure 2. Sex and age distribution of *Peromyscus maniculatus* captured near Colstrip, Montana, 1974-75. Numbers in parantheses indicate total catch.

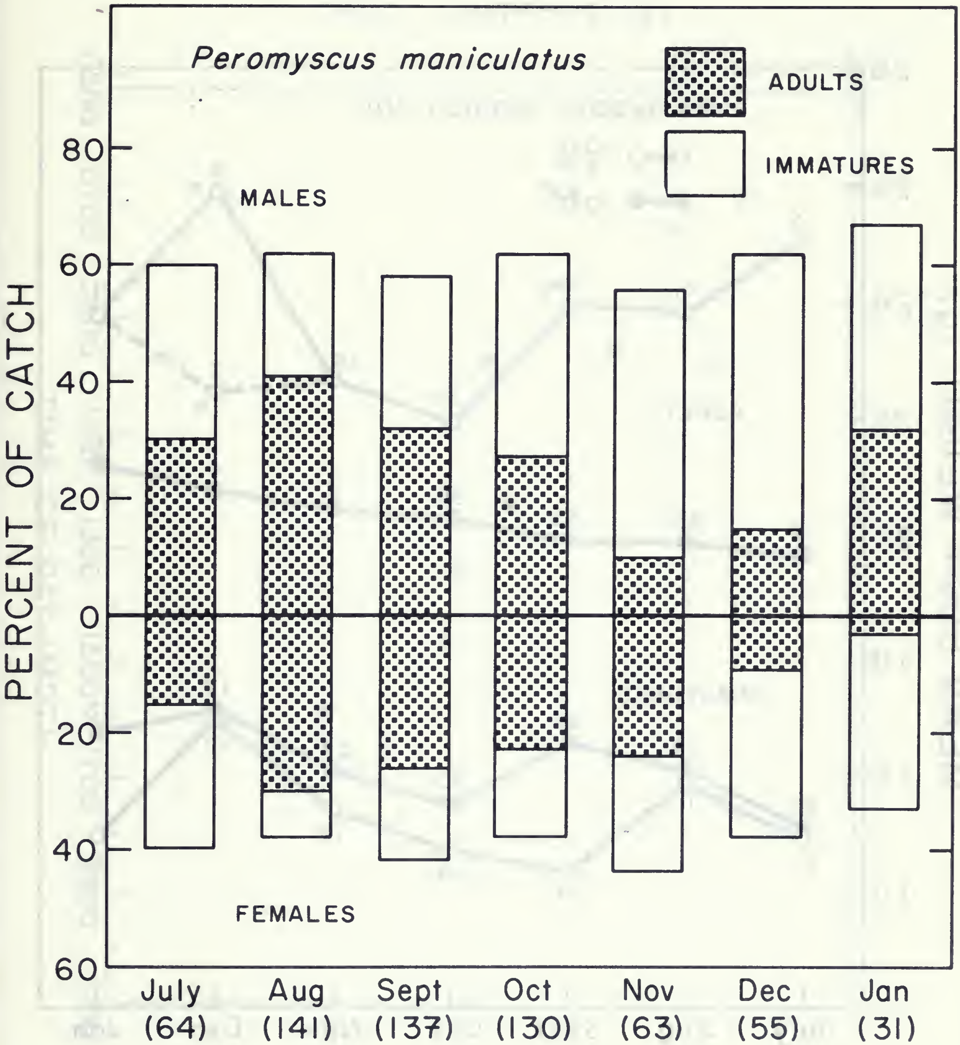


Figure 3. Seasonal changes in body weights of *Peromyscus maniculatus* trapped in the Colstrip, Montana, area. *The upper sample includes a **pregnant** female. Numbers of animals in each sample are indicated beside each point.

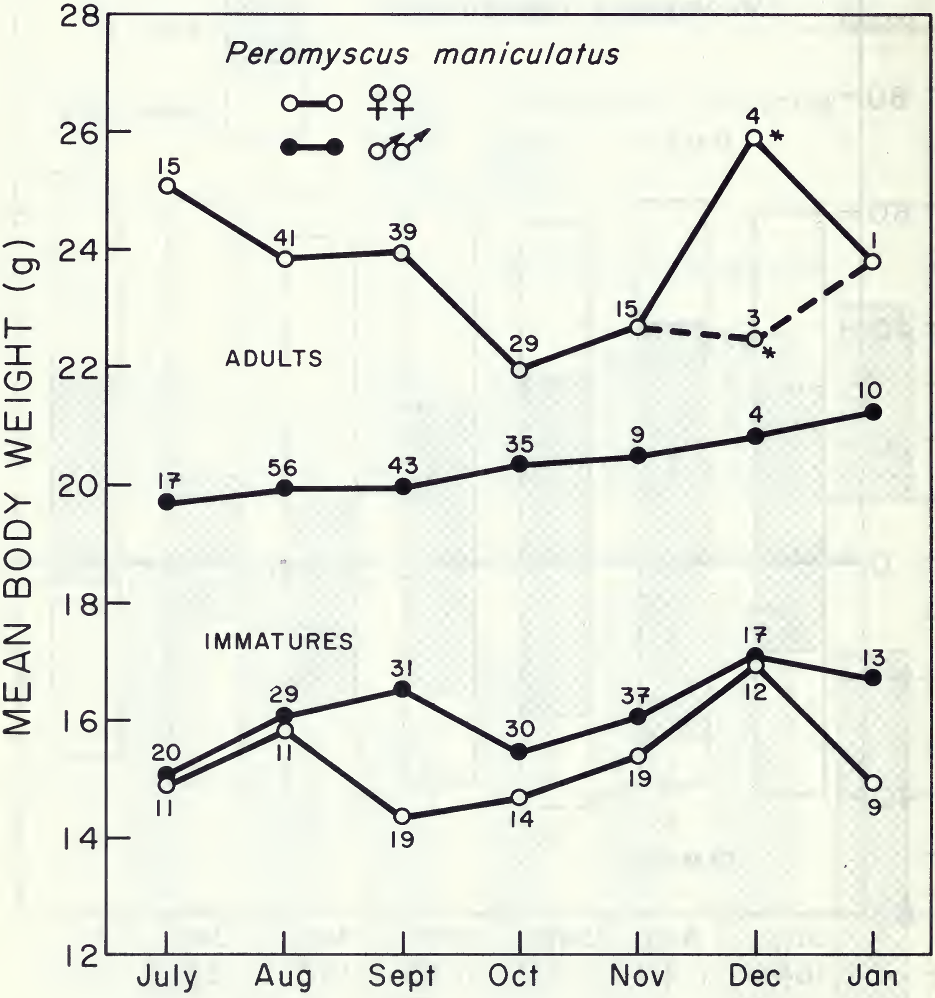


Figure 4. Daily variation in the weight of the crop contents of adult male Mourning Doves, *Zenaidura macroura*, September 9-10, 1974, near Colstrip, Montana.

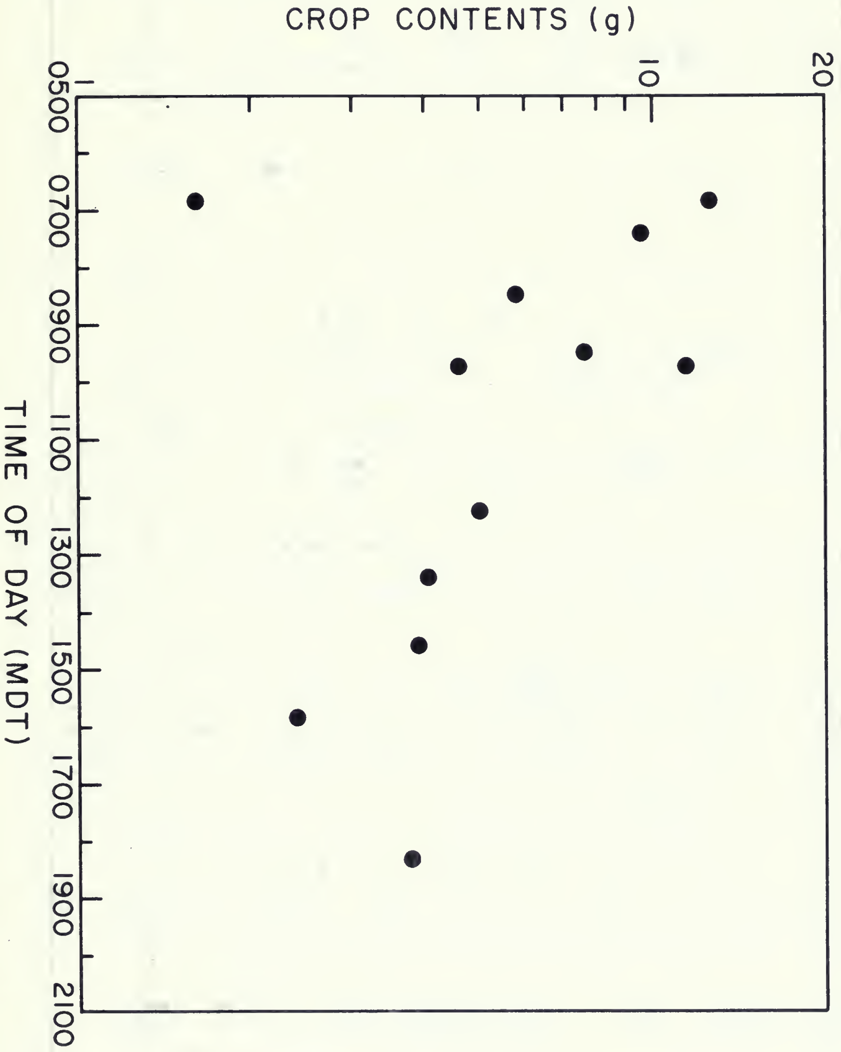


Figure 5. Seasonal progression of body weights of juvenile Western Meadowlarks, *Sturnella neglecta* in southeastern Montana, 1974.

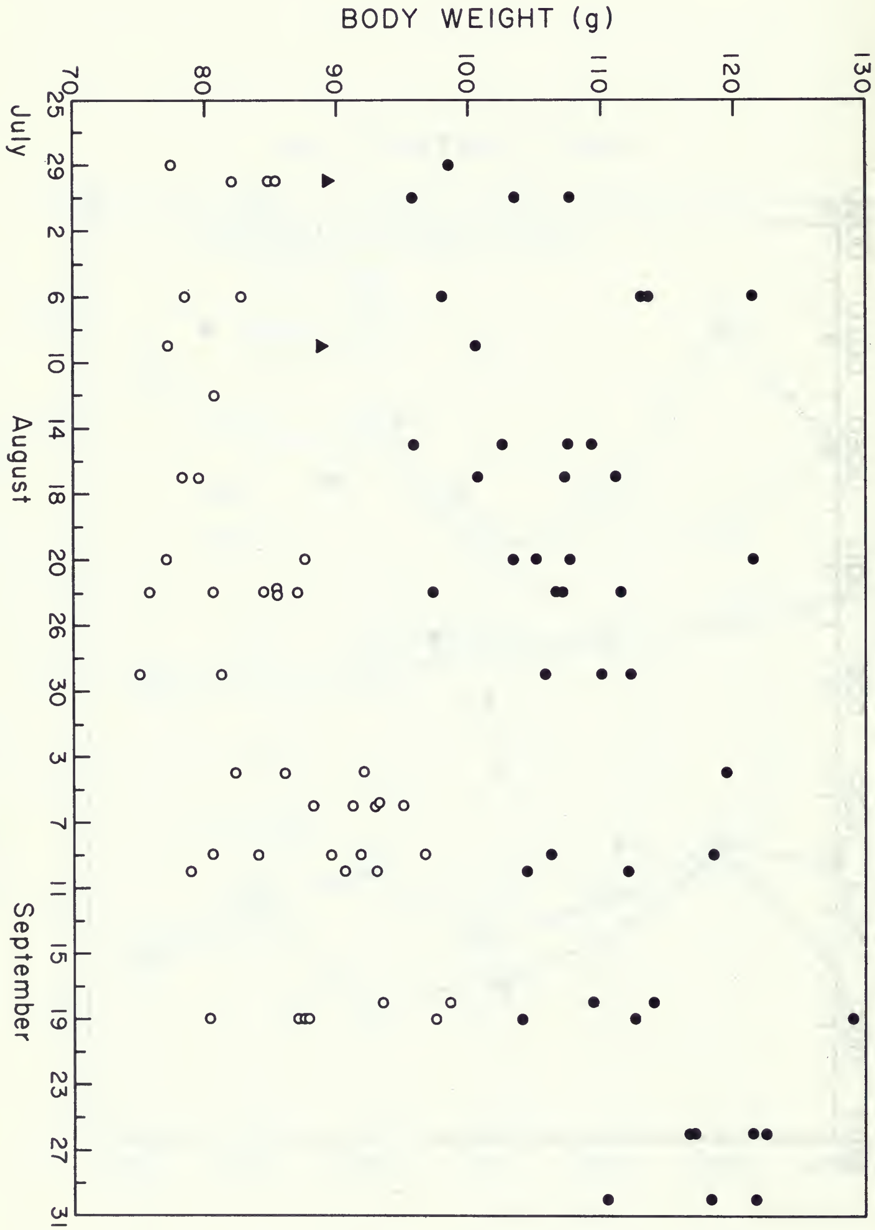
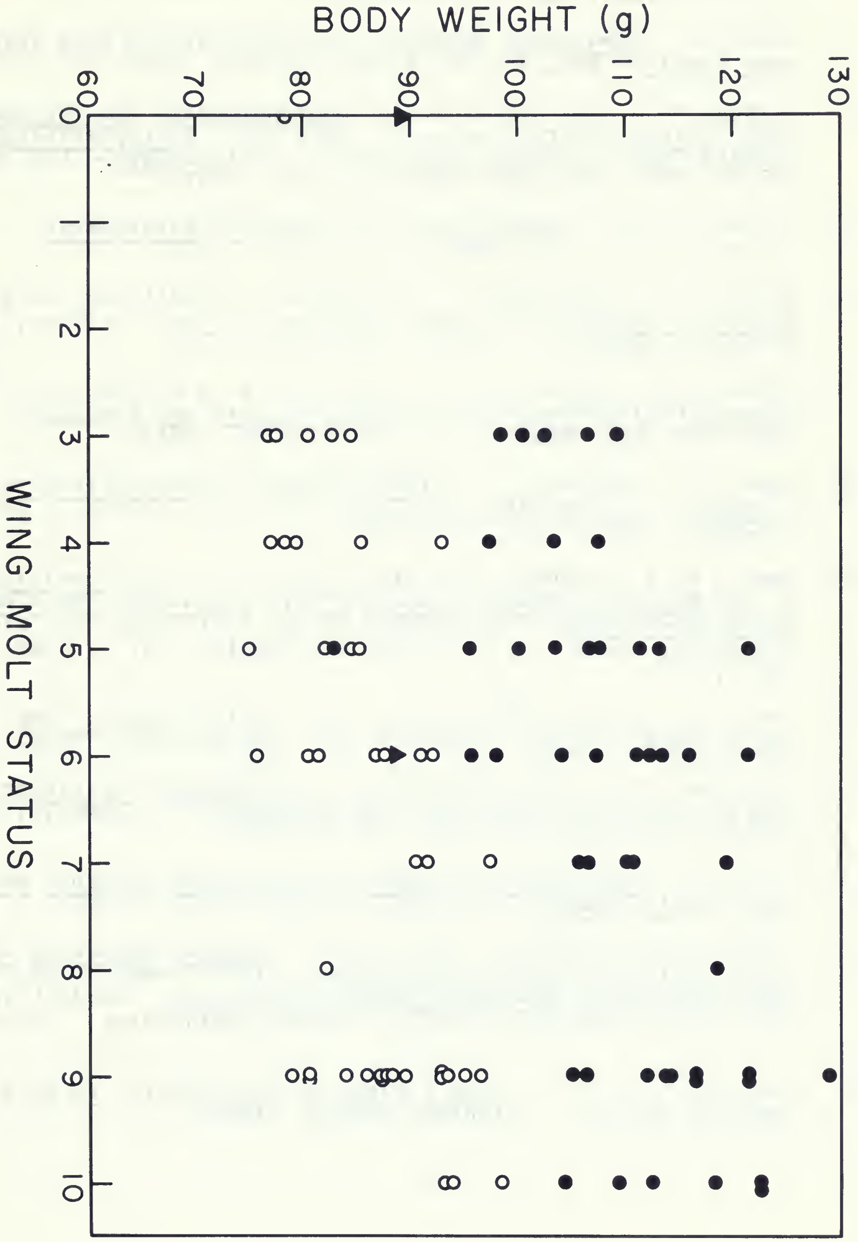


Figure 6. Body weights of juvenile Western Meadowlarks, *Sturnella neglecta*, as a function of molt stage. Stage 0 is prior to onset of postjuvenal molt; stages 1 through 9 represents the highest primary feather that is growing, and stage 10 represents birds in which the molt is complete. Molt proceeds sequentially from 1 through 9.



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Fort Union Coal Field Symposium

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BIOLOGICAL IMPACT OF AIR POLLUTION ON INSECTS

Jerry J. Bromenshenk*

Insect populations, which comprise 75 per cent of all animal species, respond significantly to air contaminants. Unfortunately, our understanding of insect-pollutant relationships is restricted primarily to studies of a few beneficial and destructive species such as honeybees and pests of forests. The extant reports consist of historical and geographical surveys of insects near industrial sources, a few laboratory fumigation experiments, and disparate biochemical and genetic studies.

Insect populations often increase or decrease in numbers in response to pollution stress. In areas of Pennsylvania subjected to elevated levels of sulfur dioxide, significant increases in the numbers of aphids (*Aphidae*) and decreases in the numbers of social bees (*Apidae*) and several parasitic wasp (*Hymenoptera*) families were recorded--the increase of aphids may have been due to a SO induced parasite imbalance (15). A highly significant relationship between an increase in tree damage by two species of needle miners, *Ocnerostoma strobivorum* (Zeller) and *Zellaria haimbachi* (Busck), and ambient and foliar concentrations of fluoride in lodgepole pine, *Pinus contorta* v. *latifolia* Engelm. was observed near an aluminum reduction facility at Columbia Falls, Montana. The data indicated that fluoride disposed the pines to insect injury (2). A negative correlation between the size of ground bettle populations and the rate of fallout of sodium sulphate existed near a Kraft mill in Canada; the change in insect numbers may have been due to SO_4^{-2} or to other particulates (13). Most ground beetles are predatory, and like their beetle allies, the ladybugs, attack noxious insects.

Some contaminants accumulate in the tissues of insects. Four major groups of insects--pollinators, predators, foliage feeders, and cambial feeders--collected near an aluminum smelter (Montana) and analyzed for fluoride content contained 58.0 to 585.0 ppm fluoride (dry weight), 6.1 to 170.0 ppm, 21.3 to 255.0 ppm, and 8.5 to 52.5 ppm, respectively. Control insects had 3.5 to 16.5 ppm of fluoride. "The relatively high fluoride levels in the 100 per cent predatory insects indicate fluorides are either accumulated by respiration or are passed along the food chain." (5) Other reports indicate that fluorides (see Figure 1), arsenites, trace elements, and fractions of particulates may accumulate in insect tissue (1, 3, 5, 6, 7, 11, 17, 18, 21, 23, 26, 28). Tissue concentrations of contaminants (and presumably their effects) vary with different insects, climate, geography, and pollution factors. Insect species, activity, age, development, feeding habits; weather patterns, wind, precipitation; contaminant species, composition, and form--all influence uptake. But contaminants do not necessarily have to be accumulated to affect insect populations either directly by toxicosis or indirectly through chain reactions among dependent organisms.

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A fallacy of many field studies of air pollution and insects has been the use of data that correlates changes in insect populations, such as mortalities, with ambient air concentrations or tissue concentrations of a single contaminant to indict the contaminant as the "cause" of mortality and even to estimate toxicity. Harm by air contaminants is demonstrated by such surveys, but the data is usually insufficient to identify a specific causal agent. Air pollution does not consist of single contaminants, but rather consists of complexes of gases and particulates that may be physically and chemically transformed during atmospheric transport. The effects of air pollution result from interactions of many contaminants. Assessments of specific, individual pollutants is largely a matter of "practical" simplification of the problem and a lack of understanding of the interactions of contaminants and other environmental factors. The total impact of pollutants and environmental stressors is not simple additive. Not only contaminant emitting sources, but other sources of environmental insults must be examined. For insect studies, a frequent confounding stressor is pesticides.

Toxicosis is usually an obvious manifestation of pollution injury. Episodic, acute exposures to pollutants may result in marked displays of insect population response such as serious losses of honeybees due to arsenic or pesticide poisonings. Figure 2 shows some lethal doeses of contaminants to honeybees. But, episodic exposure may not be as important to a biological system as chronic, low level exposures to air contaminants over periods of years. Low levels of pollutants or low toxicities do not imply low hazard to insects. Chemicals such as arsenic and the organo-phosphate insecticide, carbaryl may have little effect on foraging bees, but are accumulated in the brood--a situation analagous to control of ants in which case one seeks a slow acting, low level toxin to increase effectiveness (Dr. Roy V. Barker, letter dated March 14, 1975, USDA Bee Research Laboratory, Tucson, Arizona).

Sublethal as well as lethal effects of contaminants are important. Physiological, biochemical, genetic, and behavioral consequences of air pollution are superficially understood. Some information is available for honeybees (*Hymenoptera*), less is available for flies and midges (*Diptera*), and practically nothing is known for other insects. The toxicology of a few contaminants as insecticides (such as arsenic and carbon disulfide) has been examined although lethal dose determinations predominate, and the biochemical processes are sketchily understood for most compounds. For example, sulphuryl fluoride in eggs of desert locusts and yellow mealworms "appears" to act as an inhibitor of several metabolic processes and may be nonspecific in respect to sites of attack (22). Genetic studies of pollution effects have been restricted primarily to *Drosophila* species (fruit flies). Hydrogen fluoride at 1.3 to 2.9 ppm reduced hatchability and fecundity of *D. melanogaster*, presumably as a result of genetic damage (9). Chromosome disjunction has been induced in *Drosophila* by feeding 0.25 mg mercury (methyl mercury hydroxide/kg substrate) (23). Fumigation treatments of *D. melanogaster* for 6 to 12 hours of hydrogen fluoride (hydrofluoric acid at 2.5 per cent concentration) produced a trend toward higher frequencies of lethal and sublethal chromosomes (drastics) with increased treatment duration (20). Pollutant induced behavior modifications occur. Anaesthesia with

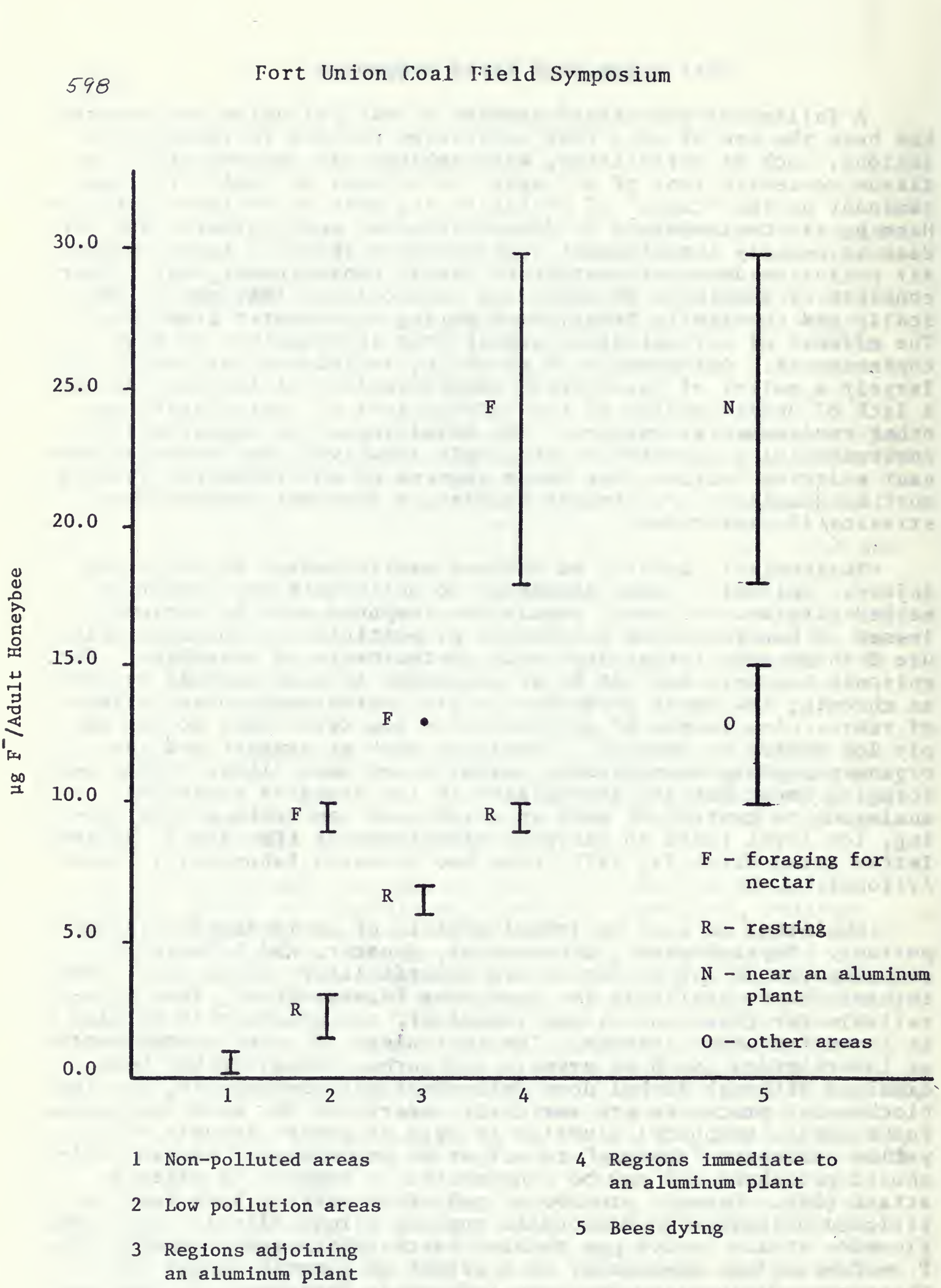
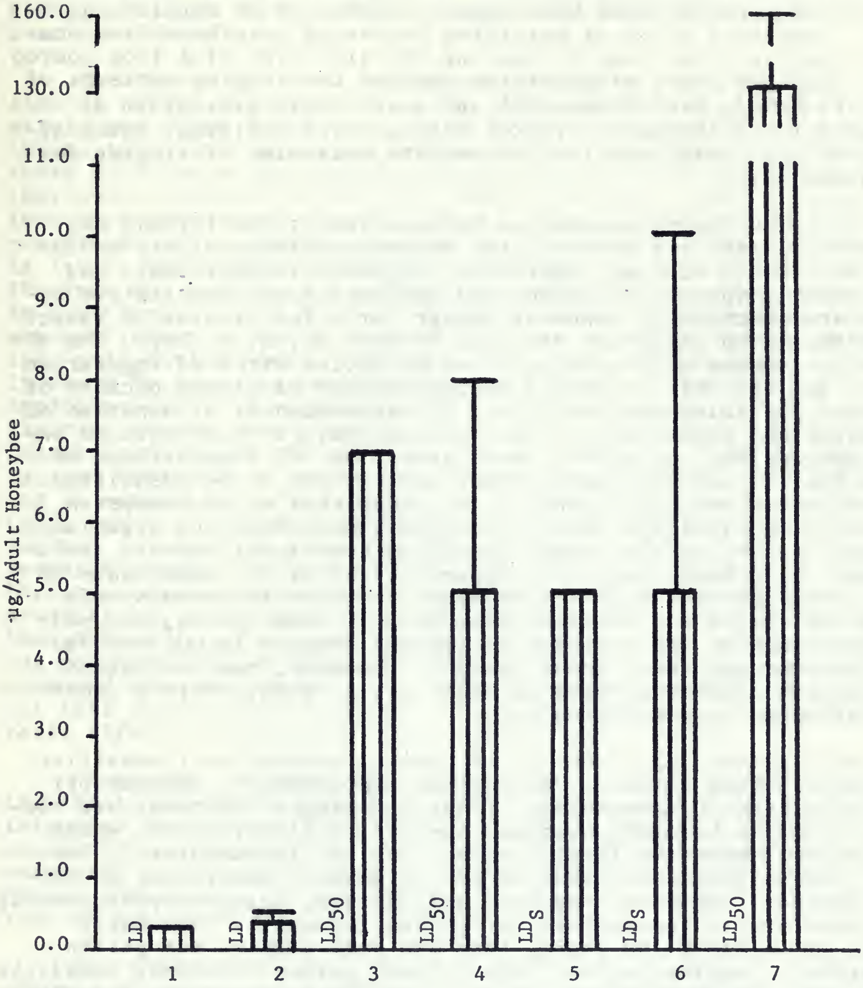


Fig. 1. Accumulation of fluorides in tissues of adult honeybees near industrial areas as reported by Guilhon (11).



1 Arsenic trioxide (17)

2 Sodium arsenate (26)

3 Potassium cyanide (21)

4 Sodium fluoride (18)
Ammonium fluoride
Ammonium bifluoride
Hydrofluoric acid

5 Sodium fluoride (11)

6 Calcium fluoride (11)

7 Sodium aluminum (18)
fluoride

Fig. 2. Comparative determinations of the lethal doses of pollutants to honeybees. Numbers in parentheses refer to authors.

carbon dioxide or nitrous oxide induced permanent changes in the behavior of honeybees--pollen collecting was reduced or suspended, while brood rearing and wax secreting were eliminated by young bees because these bees began foraging at an earlier age (24). Sublethal doses of parathion prevented honeybees from communicating to other bees by dancing the direction of a food source (27). Similar doses of parathion changed the singing patterns of crickets (*Acheta domesticus.* L.) and resulted in prevention of successful copulation by cricket males, while sublethal doses of Dieldren and Sevin resulted in complete cessation of singing for 3-6 hours (31).

Although the relationships between insect populations and air contaminants are obscure, the indirect effects of air pollution on insects such as vegetation responses to pollutants and subsequent responses by associated obligative and facultative insects are practically unknown, except for a few studies of insect infestations on pollution stressed forests (2, 3, 4, 29). The observed increases of insect pests on pollution stressed vegetation may be due to: (1) increased susceptibility of plants because of weakened physiological condition, (2) reduction or elimination of parasites and predators of the insect pests, (3) movements of insect populations to or from these areas, or (4) combinations of these factors and presumably other factors yet to be identified. Air pollution may affect only a few components of an ecosystem, yet these may initiate chain reactions among dependent organisms. Adverse impacts of air contaminants on beneficial insects (Pollinators) have been frequently reported, but it is conceivable in some instances that pollinators might increase in numbers--air pollution stress can increase flowering of some plants, and pollinators such as the social bees reflect changes in nutritional supplies through their brood rearing. However, many pollutants have direct adverse effects on bees and, as such, exert a limiting influence on population size.

Pollinators may be one of the insect systems most sensitive to air pollutant stress. Pollination (entomophily) depends primarily on bees (Hymenoptera). Flies and midges (Diptera) are second to bees in visiting numerous species of flowers (25); while butterflies and moths (Lepidoptera), thrips (Thysanoptera), beetles (Coleoptera), and other orders of insects contribute in various degrees. Bees are the best pollinators, being morphologically and behaviorally specialized for pollen transport. The hairy bodies of solitary and social bees are well adapted for pollen collection. Unlike insects that collect pollen for their immediate needs, bees collect pollen not only for their own needs, but also to provision the nest and brood. This necessitates extensive foraging and efficient collection and transport of nectar and pollen. The branched hairs on the bodies of many bees are particularly suited for carrying pollen; unfortunately they may also be well suited to the collection and transport of particulate contaminants. Obviously, the repeated and often lengthy foraging journeys of bees increase the likelihood of these insects encountering a pollution source. There is probably more information about air pollution and insect response for honeybees than for any other species of insects, but one still cannot generalize even about the responses of honeybees or of other species of bees to particular pollutant complexes. For example, susceptibility of four species of bees to field weathered insecticides occurred as follows: alfalfa leafcutter bees > alkali bees > honey bees > bumblebees. Susceptibility appeared to increase as the surface: volume ratio increased (bumblebees are as much as nine times the mass of leafcutter bees), although factors such as hairiness and behavior probably contributed (16).

Throughout the U.S. many areas already are experiencing a lack of native pollinators. S. E. McGregor says that approximately one-third of the total U.S. diet is derived, directly or indirectly, from insect pollinated crops. He quotes (14), ".... there has been an increasing accumulation of data to indicate that seed yields of insect pollinated crops can often be lower than they need to be, not because of climate, soil, or cultural practices, but simply because the population of certain insects is low," Mr. McGregor concludes that there is a need for 5 to 20 times the number of manageable colonies of bees available--an additional 2.5 to 10 million colonies (19). California growers now import honeybees from as far away as North Dakota to satisfy pollination needs. Yet honeybees cannot replace native pollinators to meet the pollination requirements of many plants. Approximately 37 species of native insects are capable of pollinating onions, but honeybees are not as effective. (Telephone conversation March 14, 1975, Dr. Frank D. Parker, USDA Bee Biology and Systematics Laboratory, Logan, Utah.) Pesticide poisoning is responsible for much of the current shortage of pollinators, yet air pollution is rapidly increasing as a contributing factor. In telephone conversations (March, 1975) with the major research groups involved with pollination and pollution research, investigators repeatedly reported observations of an absence of pollinators, especially bees, in industrial and urban areas, although hard data is often lacking to support these observations. But commercial beekeepers often do not or cannot keep honeybees downwind from industrial developments such as smelters and fossil fuel-burning power plants. It is reasonable to expect adverse effects of air pollution on other pollinators.

Obviously, studies should be initiated very soon to clarify the relationships of insects and air pollution. Again, in our telephone interviews, we could not find any research projects concerned with insects and pollution in the U.S. except for those currently in progress under the auspices of the Environmental Protection Agency, Corvallis, Oregon, in the Fort Union Basin area of Southeast Montana.

The coal-fired power plant development in Southeast Montana affords a unique opportunity to investigate some of the consequences of air contaminants on insect systems. Both forest and grassland areas occur in the vicinity of the power plant complex. A number of insect systems are available for study. Most importantly is the opportunity to conduct baseline studies before the power plants begin operation in an area that is relatively pollution free at the present time, and the opportunity to work with a multi-institution, multi-disciplinary research effort. Ongoing studies in the Fort Union area include examinations of plant communities, biomass, fungi, vertebrates, meterology, lichens, reclamation, soils, hydrology, and socio-economics. The grasslands biome project (Colorado State University) includes investigations of the invertebrate consumer components of the grassland ecosystems. Included are identification and quantification of above and below ground macro- and micro-invertebrates.

The Environmental Studies Laboratory, University of Montana, under the Direction of Dr. C. C. Gordon was awarded a grant by the Environmental Protection Agency on August 1, 1974 to conduct studies on vegetation, fungi, and insect components of the Fort Union area. My own work is directed towards the insect portion of this study. Although a number of insect systems are available for study and should be examined, it would be futile to attempt to look at all of the insects. Specifically, we selected dominant, indigenous insect-plant populations which have a diversified but understandable relationship. We considered feasability, biological importance, and economic impact. Certain insect populations are sensitive indicators of pollution stress, and these appeared to have the greatest potential for supplying useful and understandable information. Consequently, the insect work has been concentrated on two groups: pollinators, and infestations on Ponderosa pines by pest insects. Both showed specific responses to air contamination in previous studies, appear to be very sensitive pollution indicators, are economically important to the region, and are manageable for research purposes.

Commercial honeybees are important to the economics of the Colstrip, Montana area. Approximately 3,000 colonies of honeybees are maintained in the Fort Union Basin. These colonies provide bee products such as honey and wax, are valuable pollinators of alfalfa seed crops, and at least 1,000 colonies are transported annually to California (October through April) and rented for pollination of crops. At a very conservative estimate, the honeybee industry comprises a $240,000 to $300,000 enterprise (at a value of $80-100 per colony for bees and products). Floyd Moeller, research leader of the North Central States Bee Laboratory, Madison, Wisconsin, estimates the actual economic value of honeybees as pollinators at 20 times their value as honeymakers. This means that the honeybees in Southeast Montana may be worth $3-4.5 million as pollinators of rangelands and agricultural lands in Montana and an additional $500,000 to one million dollars as pollinators of California crops. (Data based on marketable honey yields from 1,200 colonies in the Fort Union Basin, confidential report.) In addition to honeybees, native bees are plentiful in the Colstrip area as evidenced by my observations in August-October of 1974. Currently, native bees may be capable of satisfying the pollination needs of most of the vegetation of the Fort Union area. However, evidence from insecticide problems indicate that the native bees, especially the physically smaller species, may be much more susceptible to pollutant toxicosis than honeybees.

The manageability and numbers of honeybees in the study area make them an excellent tool. We obtained samples of adult honeybees from thirteen apiaries in October of 1974 for chemical analyses. We have completed fluoride and sulfur analyses, have obtained partial results from pesticide analyses, and have a bank of fresh frozen and dried material for additional chemical analyses. The baseline levels of contaminants in this area appear to be low: fluorine averaged 7.4 ppm dry weight, SD=3.1, in adult bees (unpublished data), which compares favorably with the 10.0 ppm found in control bees for the Columbia Falls study (5). The mean sulfur content was 4392 ppm, SD=286. Sulfur occurs as a natural portion of animal tissue, and there appears to be some question as to whether or not it is accumulated, although exposure to SO_2 at 8.2 ppm for three weeks increased sulfate in honeybee haemolymph by a significant amount (12). Pesticide analyses being conducted in cooperation with this project by Dr. Ronald Thomas, EPA, Biological Investigations Laboratory, Beltsville, Maryland, revealed the presence of low level residues of chlorinated hydrocarbons in bees from four sites. Some 700-800 colonies of bees were killed in the Fort Union area in 1974, presumably as a result of pesticide poisonings. Pesticide poisonings. have occurred previously in this area, and therefore it is essential to consider this pollutant source with that of the air contaminants emitted by the power plants. We shall continue these chemical analyses over the next 2-3 years, after the power plants have become operative. We intend to perform analyses for trace elements as well as to utilize AchE determinations as an index of sulfur interaction.

Our approach to the bees will be as inclusive as possible. We shall monitor behavioral responses through the use of observation beehives and a ferrous-metal capture-recapture system. The latter (8) consists of small metal tags that are affixed to bees and collected at monitoring points by magnets. This method is particularly useful for monitoring foraging activities. We shall monitor biopathways of pollutant uptake through the use of pollen and dead bee collectors and conduct fumigation experiments at the EPA zonal air pollution delivery system in Southeast Montana and in the laboratory. Finally, we shall examine indications of physiological conditions such as brood rearing, colony activity, and colony size.

Our work with the pest infestations on Ponderosa pine is concerned with: (1) estimates of the endemic insect and pollution damage being sustained by the pines, (2) comparisons over the next few years to determine if insect damage has appreciably increased, and (3) if this increase correlates to a significant degree with foliar and precipitation content of pollutants such as fluorides and sulfurs. The condition of the pines is rated via a vigor rating which takes into account factors such as needle retention, needle necrosis, and other physiological symptoms of pollution stress. Our data from 1974 indicates that insect damage in the area was usually very slight, with the exception of fairly severe loss of seed production because of cone boring insects such as *Conophthorus* beetles and *Laspeyresia* and *Dioryctria* moths. This type of damage affects seed production but does not appreciably injure the tree itself. Several studies have shown significant correlations in the relationships of pest damage and foliar and ambient air concentrations of air contaminants. However, these studies have always relied on data obtained after the source of the contaminants has been in operation for extended periods of time. Therefore, whereas the level of pollution and the size of the insect populations may correlate, the total impact or extent of the increase over that of an "undisturbed" situation is unknown.

Obviously, other insect systems should be investigated in Southeast Montana. One of the more significant systems is that of the western harvester ant. Another consists of the grasshopper populations which periodically have been severe pests of the rangelands. The "Applicant's Environmental Analysis" (30) recognized the following economically important insects and arachnids present in the impacted area: Rocky Mountain ticks, mosquitos, fleas, and deer flies as vectors of human disease; pine beetles, larch casebearers, spruce budworms, and mountain pine beetles as forest pests. The applicants made no mention of agriculturally important insects such as pollinators and those species predacious or parasitic on invertebrate pests.

The Fort Union development provides an excellent opportunity for field experimentation. Unfortunately, since the shakedown operations of the power plant complex will begin this spring (1975), baseline data should already have been obtained, In some instances it has. Studies of insect population response should be oriented towards field investigations. Laboratory studies have value, but laboratory results do not necessarily correspond to events in the much more complex environment of an ecosystem. For example, exposure to 5,000 rads of gamma or neutron irradiation reduced by 21 per cent the life span of worker honeybees housed in laboratory cages. Yet, when an entire colony was irradiated with 5,000 rads and returned to the field, the bees perished (10). Most researchers are cognizant of the problems associated with conducting field experiments in complex environments. Oversimplification of the field environment as a "control" measure, in essence, establishes a quasi-laboratory condition. Cultivation of noncultivated plants, irrigation of plants normally receiving only natural rainfall, elimination of insect pests, transplantation of plants to areas in which they would not normally occur, destructive sampling--procedures such as these simplify testing but may invalidate extrapolation of results to the real world. Field controls ideally consist of natural sites in which confounding factors are identified and monitored, not eliminated. Hopefully, this can be accomplished in the Fort Union Basin.

There can be no doubt that air contaminants affect insect populations, although the exact processes are not understood. It is reasonable to expect biologic and economic costs of air pollution stress. We need to know at what level of pollution the economic and biologic consequences are important as well as to identify the effects. We must assess the actual significance of insect populations, beneficial and destructive, to the Southeast Montana ecosystems. Ultimately, biologic impact is expressed in terms of economic impact. Who pays for destructive insect infestations to forests? What is the cost of replacing or supporting pollination systems by importing insects such as now occurs in California? What are the consequences of a lack of pollinators to plant diversity and abundance on rangelands and eventual impact on the cattle industry? What is the impact of increased foliage feeders such as aphids on agricultural crops? These are but a few of the questions that need to be answered. Unfortunately, we will not answer any or all of these questions without intensive long-term studies. Evaluations of pollution impact must be tested by gathering baseline information under "pollution free" conditions. Areas in which this can be done are becoming increasingly difficult to find. The Fort Union

Basin afforded one such opportunity, although advance notice was not sufficient to allow long-term baseline studies. Obviously, we cannot accurately predict the location or intensity of new pollution sources. Therefore, we need to find undisturbed areas and conduct baseline studies while such areas are available. S. E. McGregor, in a recent synopsis of the significance and research needs of insect pollination, stated: "Many....crop varieties grown today have never been tested under insecticide-free conditions to determine the actual value of the pollinators unhampered by damaging pesticides" (19). Considering the worldwide distribution of pesticide use, one must ask if a totally insecticide-free area exists. The same may soon be true for pollution-free areas.

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A FIELD EXPERIMENTAL SYSTEM FOR THE EVALUATION OF THE BIOENVIRONMENTAL EFFECTS OF SULFUR DIOXIDE

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INTRODUCTION

The Environmental Protection Agency's Montana Coal-fired Power Plant Project has, as a major objective, the generation of a protocol that will allow managers to assess the impact of energy producing activities on the environment prior to the initiation of construction activities. The field experimental component of this project is expected to provide data essential to the construction of such a protocol. In particular, we hope to establish both the specificity and threshold of the effects of sulfur dioxide on well-defined components of a grassland ecosystem. We hope also, by correlation of results of the field experiments with those near Colstrip, Montana, to evaluate the site-specificity of these responses. Finally, during the three years of the investigation, we hope to generate predictive or extrapolative models that will link short-term low threshold effects to those that occur only after prolonged exposure.

The field experimental component of this investigation will take place at a grassland park located in Custer National Forest in southeastern Montana. Experimental stressing of four one-acre plots will be initiated in May 1975. These plots are situated within a 27 acre exclosure to protect livestock from injury, and to protect equipment from damage by livestock.

These experiments are designed to test the effects of SO_2 upon plant and animal (arthropods) biomass dynamics, plant community structure, insect and fungal disease of plants, pollination systems, sensitivities of lichens, and upon a number of physiological and biochemical functions. Dominant plants on the study plots are Western wheatgrass (*Agropyron smithii*), prairie junegrass (*Koelaria cristata*), and Sandberg bluegrass (*Poa secunda*).

We plan is to maintain different sulfur dioxide concentrations on each of these plots. The system herein described was designed to allow us to maintain a constant 30 day median concentration on each plot during the entire growing season (circa April - October). Continuous monitoring of gas concentrations will insure that the desired levels are maintained. Application of a Gaussian dispersion model (20) indicates that even under unfavorable dissipation conditions, concentrations about 200 feet from a 40 pphm plot will remain below 5 pphm.** The effects on surrounding areas will thus be minimal and significant levels will not occur outside the study enclosure. A log-normal distribution of concentrations about the mean is expected and desired because this type of distribution pattern occurs frequently. Preliminary testing of a proto-type system during

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**pphm=parts per hundred million.

September 1974, indicated the feasibility of this type of control.

DESIGN REQUIREMENTS

The ultimate design goal is to provide a system for the unambiguous assessment of the impact of sulfur dioxide on otherwise undisturbed grassland ecosystems. We have approached this ideal by establishing realistic ecological and physical criteria.

Disturbance of biota and of micro-climates by the system must be minimized. Effects on incident radiation, prey refuges, ground level obstructions and pathways, temperature, humidity, wind and other features of the micro-habitats must be kept as small as possible. The area to be stressed must be large, on the spatial scales of the populations to be sampled, to reduce edge effects and to assure adequate population and sample sizes. The areas chosen for comparisons (i.e., "treatments" and "control") should be as nearly uniform as possible in habitat, edaphic, and terrain features.

The distribution of pollutants must meet certain spatial and temporal constraints. Concentration should follow a log-normal distribution similar to those which occur in polluted areas (9). The distribution should be spatially uniform or nearly so, at least on a time average basis. In particular, there should not be any "hot" or "dead" spots and concentrations must be controllable for a range of selected averages.

Finally, cost, maintenance, and operation must be reasonable.

The system that we have designed meets these criteria. Each study plot has a 1 ¼ acre network of one inch pipe supported above ground level by pipe stakes. The centers of the plots are located along a line, with buffer zones between plots wide enough to prevent interference between plots (Figure 1). A dilute mixture of air and SO_2 flows through the lines and is released at numerous points over the grid.

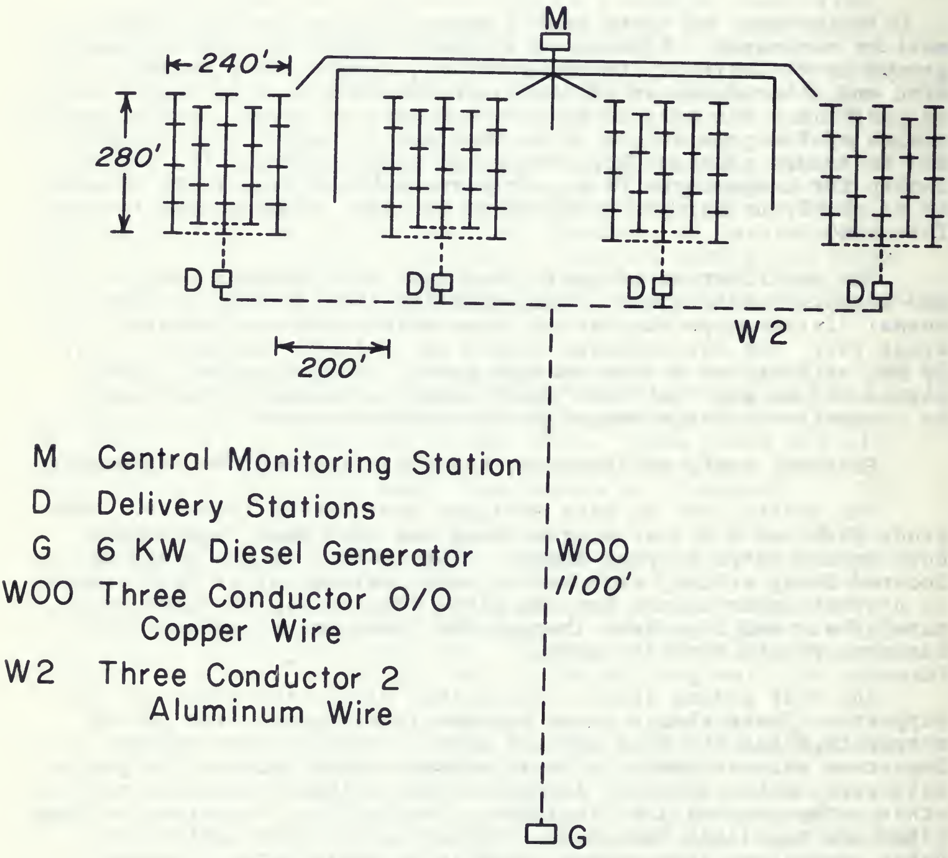
The only ground level obstructions within the plots are the supports. These should cause minimum interference with animal movements, while the pipe network itself should cause minimum impact on micro-climate. The relatively small size of the plots will exclude the study of large animals, although insects and other arthropods will be included. In addition, the areas between plots are available for study, although under less easily evaluated conditions, thus making possible a limited study, perhaps, of small rodents. The contiguity of the plots allows for nearly uniform habitat conditions.

By utilizing many small, elevated, point sources, adequate dilution of SO_2 at ground level is insured and, in effect, an area source is created. This prevents step-function changes in concentrations in time and space. Testing of the system, as described below, confirmed our expectations regarding the nature of the distribution.

PROTOTYPE RESULTS

A full size prototype of the Zonal Air Pollution System (ZAPS) was constructed and employed to test the feasibility of

Figure 1. Schematic of the first four Zonal Air Pollution Systems, showing the individual delivery systems and the common monitoring and electrical systems.


M
240'
280'
D
D
D
D
W2
200'
WOO
1100'
G
M Central Monitoring Station
D Delivery Stations
G 6 KW Diesel Generator
WOO Three Conductor O/O Copper Wire
W2 Three Conductor 2 Aluminum Wire

this experimental approach (Figure 2). This prototype system was tested in the field during October, 1974.

Gas delivery lines of the prototype were constructed of one inch mild steel pipe set parallel to the ground and supported at twenty foot intervals by five foot pipes driven three feet into the ground. Release points (1/32 inch holes) were situated at ten foot intervals. Sulfur dioxide was bled into a continuous flow of air provided by a helical compressor. Equipment was housed in a heated shed with the temperature kept high enough so that the vapor pressure of the SO_2 in the tanks was always above the desired release pressure. Pressure regulators on the tanks and a flow controller at the injection point, assured the desired flow rate of SO_2. Air pressure in the lines (about one psig) varied by less than 5% across the system.

Sulfur dioxide was monitored by recording the output of a sulfur analyzer in the logrythmic mode. Eight sample lines fed into a time-share device so that each line was sampled for ten of very eighty minutes. The ends of four of the lines were moved to various positions within the plot, while one line always sampled the center of the plot. The remaining three lines were placed outside the equipment shed. All sample points were located approximately one foot above ground level.

Wind speed and direction were recorded frequently each day. The weather was generally clear and mild during the test period. Daily highs were in the 70's (Farenheit) and lows in the 40's.

TEMPORAL VARIATION

Data on the temporal variation of concentrations were obtained mainly from the central sampling point. In models of pollutant dispersion source strength appears as normalization constant with the patterns of distribution determined by meteorological conditions (9). The frequency distribution of concentrations of the central point was obtained by pooling all data from this point, after normalizing to the most common source drain (i.e., SO_2 flow rate). The results (Figure 3) clearly demonstrate that the concentrations were log-normally distributed with a geometric mean (GM) of 5.2 pphm, a standard geometric deviation (SGD) of 2.1 and an arithmetic mean of 6.5 pphm. Typical values for five minute averaging times of GM and SGD (9) are given in Table 1. Note the relatively low variability of SGD over a range of geometric means, reflecting the independence of SGD and source strength. The values obtained by the prototype are consistent with these data. The main point is not that the system simulated a particular place (i.e., Philadelphia, 1962-1967, Table 1) but rather that the concentrations across the plots are adequately controlled at the low levels desired. Conditions within the plot mimic either locations subject to area sources or locations some miles down wind from point sources. Changes in average concentrations associated with changesin wind direction from a point source can be simulated simply by adjusting the SO_2 flow rate.

Typical time series for the central and two other sampling points, located near opposite corners of the plot, are shown in Figure 4, which contains only un-normalized data. The main features are the two peaks, one near sunrise, and the other after sunset, The three sample points generally track one another

Figure 2. Geometry of the prototype delivery system.

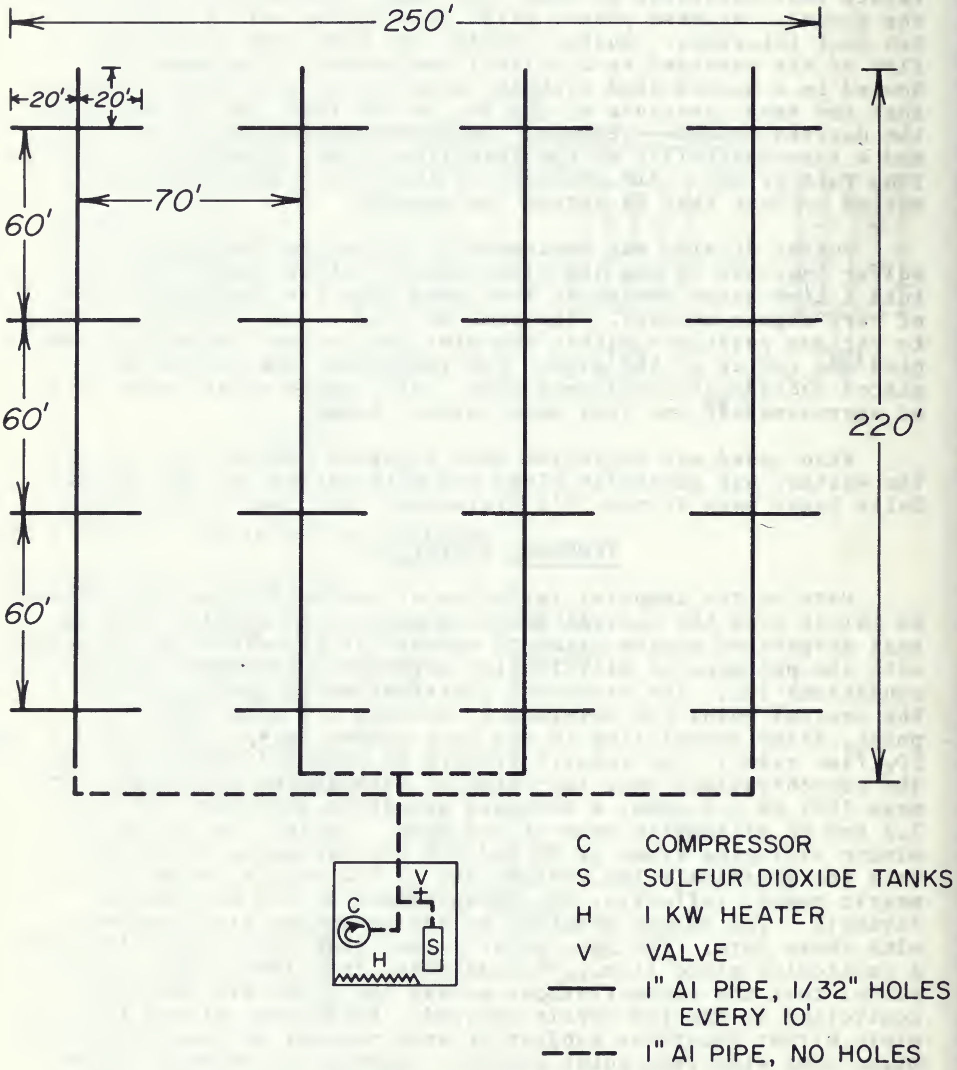


Figure 3. Distribution of concentrations on the prototype.

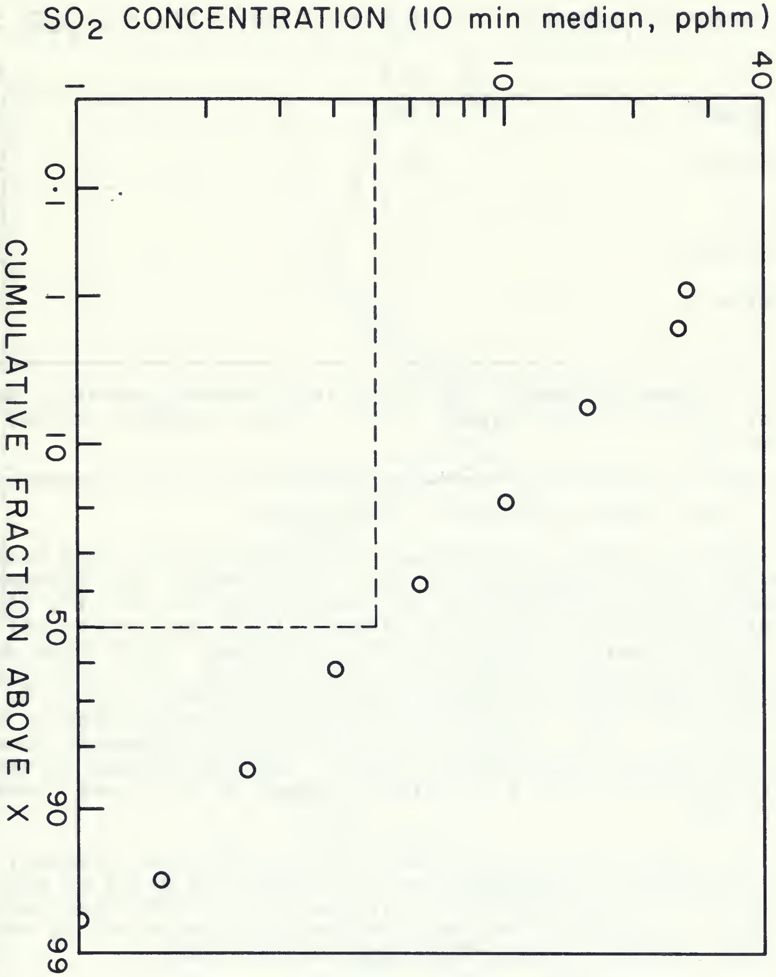


TABLE 1

City	GM	SGD
Chicago	10.4	2.2
Cincinnati	1.6	2.9
Denver	1.3	2.1
Los Angeles	1.3	2.3
Philadephia	5.5	2.4
St. Louis	2.8	2.8
San Francisco	0.5	2.9
Washington	3.9	2.2

Table 1. Geometric means (GM, pphm) and standard geometric deviations (SGD) for urban areas. Five minute averages, 162-67 (source: 9).

although some phase differences are evident.

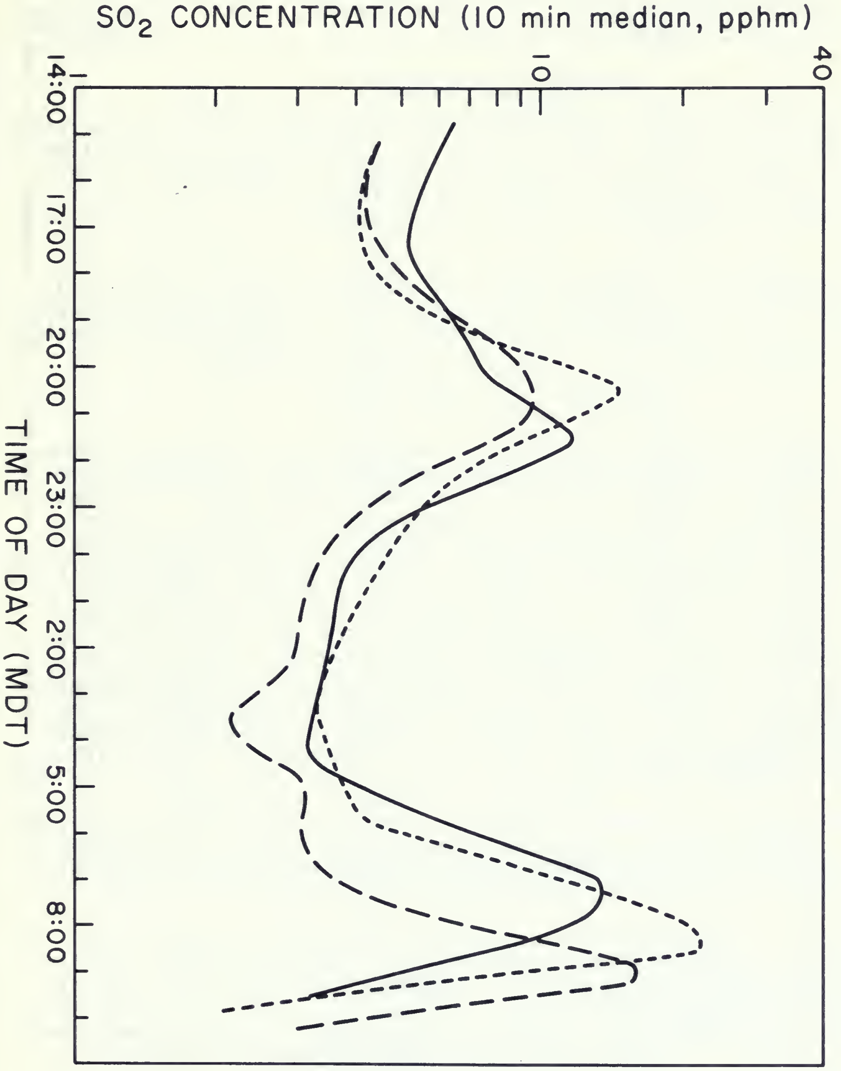
Diurnal patterns of pollutant SO_2 concentration from both stationary point sources and in urban environments are frequently similar to that produced by our system (10, 13, 15, 17, 18). Such variation in air pollutant concentrations are due to (a) variations in source strengths that in turn may result from daily cycles in human activity (6, 10); (b) transport wind speeds and directions, atmospheric diffusion and interactions, (2, 5, 6, 10, 11, 12, 17). All of these vary as a function of weather and season (1, 3, 5, 19). Atmospheric dilution is frequently greatest during the day and least at night. This may result in one or more daytime maxima and a nocturnal minimum in pollutant concentration (10).

While they have yet to be well defined for most systems, diurnal and annual differences in the ability of biota to withstand pollution challenge may be pronounced (8) thus the time of occurrance of daily and seasonal maxima may be expected to condition the results of our field experimental study.

SPATIAL VARIATION

Concentrations varied systematically and smoothly over the plot. Regions near the delivery lines tended to have values up to three times higher than regions midway between the lines (Figure 4), although there did not seem to be any "hot spots" associated with the release points. Concentrations generally increased in the direction of the prevailing wind and decreased at a moderate rate outside the plot proper so that concentrations twenty to fifty feet beyond the plot border were comparable to those within the plot.

Figure 4. Time-series of concentrations on proto-type, October 12, 1974. Points are center(----), generally downwind (——), and generally upwind (— — —). Latter two were nearer the lines than the central point.



MODIFIED DESIGN

Figure 5 represents an improved ZAPS geometry. This design includes (1) a higher density of release points, (2) more dilute SO_2 in the lines and (3) lines placed two and one half feet above ground to promote better dilution and mixing. These features should eliminate the "dead spots" located halfway between the sulfur dioxide distribution pipes and should produce a more nearly uniform distribution of the gas.

EXPERIMENTAL DESIGN

Four of the new systems are being built and will be separated by 200 foot buffer zones (Figure 1). Air only will be released on one plot that will serve as a control. The median SO_2 concentrations will differ on each of the other plots. We expect interference between the plots to be minimal.

The new systems are being constructed of aluminum for corrosion resistance. One plot will be monitored extensively while the others will be sampled at a single point. Power will be supplied by a 6 kw diesel electric generator situated approximately eleven hundred feet down wind from the nearest plot.

APPLICATION OF THE SYSTEM

At this writing, the first set of Zonal Air Pollution Systems (ZAPS) is nearing operational readiness and treatments are about to begin. We expect to deliver SO_2 continuously throughout the growing season, which we define operationally. Treatments will begin in the spring when the 10 day running average of air temperature exceeds 5.0°C and will terminate when the ten day running average falls to 5.0°C. The reason for selecting this criterion is based on observations in the literature that plants with the C_3 Calvin-Benson pathway of CO_2 fixation can be quite active at 5°C. The dominant plants on the fumigation site are C_3 species. The rationale behind the 10-day moving average is simply to insure that we will not be either beginning or ending fumigation in response to brief periods of unseasonal weather. In a typical year, we thus expect to fumigate from about mid-April through October.

Based upon our estimates of the daily and seasonal variation in SO_2 concentrations to be expected from ZAPS and best guesses on the effects of peaks-biota interactions, we propose to maintain median concentrations as indicated in Table 2.

Given this design, we anticipate measurable, identifable SO_2 effects on the plot with the highest concentration. SO_2 levels on this plot will frequently approach or exceed the present secondary standard of 0.50 ppm (1300 $\mu g/m^3$). This is the maximum three hour concentration that is not to be exceeded more than once each year. We feel reasonably assured that biological effects will occur at the five pphm median level (4, 7, 14, 16), and liminal effects might be seen as low as 2 pphm.

SUMMARY AND CONCLUSIONS

The gas delivery system that we have described in this communication was designed to simulate actually occurring

Figure 5. Improved delivery system geometry.

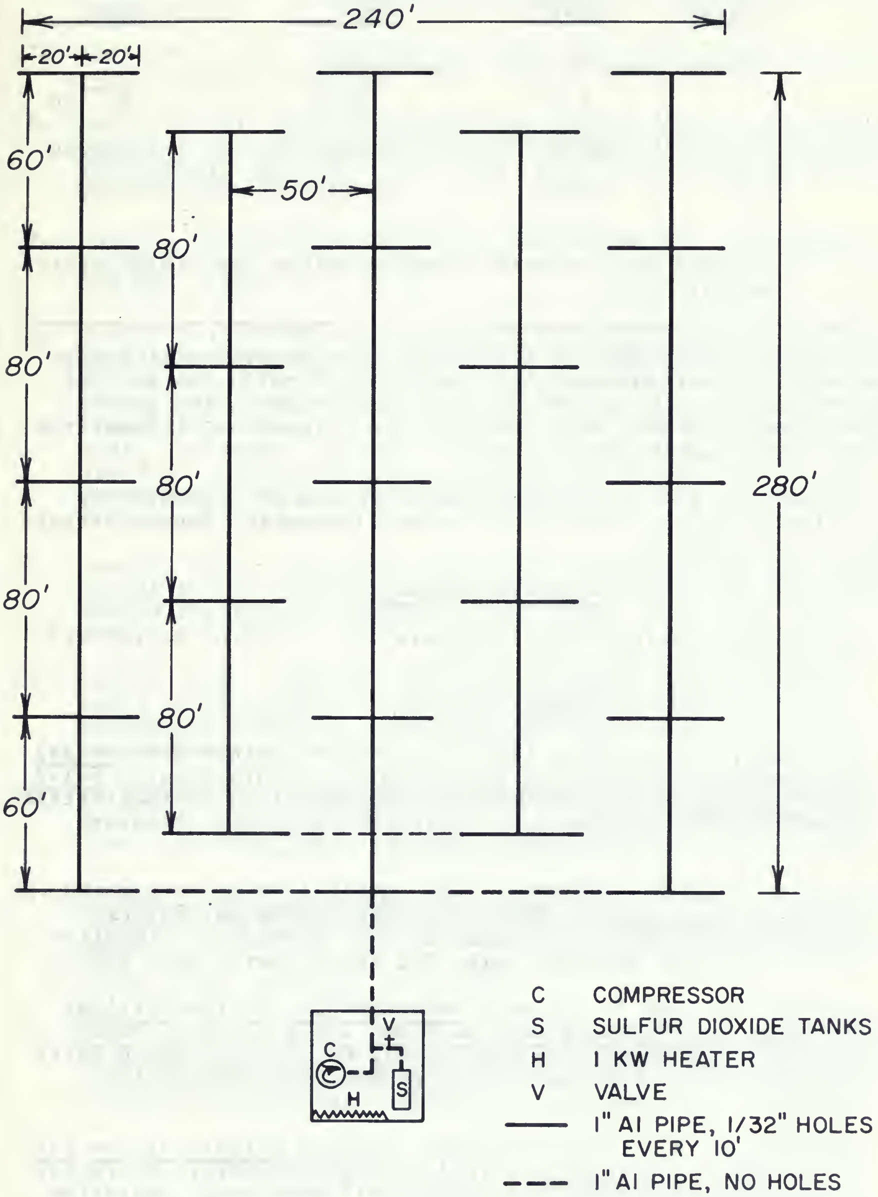


TABLE 2

Plot	5-Minute Median	Daily 3-hour Peak	Probable Growing Season Peak	Possible Seasonal Peak
1	0	0	0	0-2
2	2	8-10	15-20	90-100
3	5	20-25	40-50	100-200
4	10	40-50	100-200	400

Table 1. Expected SO_2 Concentrations (pphm) on the Field Experimental Plots.

anthropogenic environmental pollution. The experimental design deals with the multidimensional character of pollution and the complexities of natural communities. Furthermore, the gas is delivered with minimal alteration of the climate or microenvironmentas of the sampled ecosystem.

We believe that this experimental system as presently applied offers a good potential for bioenvironmental impact assessment and forecasting.

ACKNOWLEDGEMENTS

Technical assistance in the operation of the prototype system was provided by Mr. Larry Doe.

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MONITORING THE RANGE RESOURCE IN THE VICINITY OF COLSTRIP, MONTANA

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INTRODUCTION

We all agree that air pollution standards should protect human health. Many feel that the integrity of plant and animal communities should also be protected. As a plant ecologist, I fall into both of these groups.

Green plants are generally referred to as the indicators of air pollution insult. Wild and domestic animals are restricted in their movements, however, and can also serve as indicators of pollution. In many cases they serve this function better than plants since they accumulate certain pollutants and dramatically display their effects more vividly than any plant.

Animal tissue levels of specific pollutants as well as plant sensitivity levels should be primary factors influencing stationary source emission standards. Unfortunately, our knowledge of the effects of the most obvious pollutants--sulfur dioxide, fluorides, and nitrogen oxides--upon plants is very limited. The much more complex effects of the numerous trace elements upon plants and animals has only begun to receive attention.

In the absence of sound scientific knowledge state and federal air pollution criteria, be they ambient air or emission standards, are assigned as single standards. They are blanket applications applied to air pollutant sources with little regard to factors such as sensitivity of biota to pollutants or potential for pollutant accumulation in food chains.

The effects of long term exposure to sulfur dioxide, nitrogen oxides, fluorides, and trace elements upon plants in the Great Plains is unknown or vaguely conceived. Some worthwhile research has been undertaken in the more arid regions of Colorado and Arizona by Davis and Hill (5, 9) on the effects of sulfur and nitrogen oxides on desert plants, but their studies were of short duration, took place in desert regions, and emphasized only one or two pollutants. The emissions of coal burning installations are not restricted to sulfur dioxide and nitrogen oxides alone but consist of a whole series of chemicals which may or may not be toxic to plants and animals. Furthermore, exposures will not take place over a few hours or days but over the entire lifespan of the organisms.

THE STUDY

In 1972 the Agricultural Experiment Station of Montana State University was contracted by the Montana Power Company to undertake a thorough study of the range resource in the Colstrip vicinity. The ultimate objective of this study was to determine whether stack emissions from the coal-fired generating plants at Colstrip damage vegetation or animals and thus effect the economy of the local livestock industry or crop producers. The investigation was designed to be a long term project covering a preoperational phase of baseline data gathering and a postoperational study conducted during power plant operation.

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Our task was not concerned with the determination of the concentration of any pollutant in the atmosphere, but was to investigate the possibility of airborne pollutant effect on the range resource and to define parameters that would measure this effect if it occurred. We were to define those characteristics of the range resource most likely to be influenced by stack emissions and establish baseline information concerning those parameters prior to operation of the power plant. The general objective of the study was narrowed to three specific aims. One, determine the effect of stack emissions on range forage production; two, identify, isolate, and quantify contaminants occurring in herbivores, the important plant species, and in the soil system; and three, identify major vegetative or animal accumulators of potential toxic emissions. The identification of potential emissions and possible sites of accumulation was included in this final objective.

Experimental Design

To facilitate the study, a sampling network of over 70 collection sites was established on eight radii extending from the Colstrip plant. Those radii extending along the windward axes were sampled at intervals from 1.6 to 32 km (1-20 miles). The other radii were only sampled to 12 km (7.5 miles). Four exclosures have also been established with 7.2 km (4.5 miles) of the power plant site.

At each of the sites on the grid, surface soils were collected and quarterly samples of the dominant vegetation have been clipped since the fall of 1972. Several samples have been collected at each grid point. They include individual species of grasses, forbs, and shrubs if present in numbers sufficient to support such sampling as well as a common sample of perennial grasses and forbs. Woody species such as Ponderosa pine, willow, and cottonwood have also been collected where available.

Elemental Study

The trace element content of over 30 samples of coal from the Rosebud seam at Colstrip, Montana has been determined at Montana State University and elsewhere. Elemental levels averaged from 0.2 ppm mercury and cadmium to 30 or more ppm fluoride, nickel, and manganese. Lead, arsenic, selenium, copper, and zinc were also present in the coal samples. The ultimate fate of these elements as well as sulfur and nitrogen oxides formed by combustion of coal are the immediate concern of ranchers, power company officials, and others working in the Fort Union Basin. They constitute the main thrust of our study.

Selection of potential elemental emissions of major concern was based upon presence of the element in coal samples in quantities sufficient to warrant study, established biological activity, and toxicity to plants or animals. Sulfur and fluoride were the most obvious components of the coal to be studied. They fulfill the three prerequisites for study mentioned above. Analyses for copper, zinc, and manganese were carried out despite the essentiality of these elements to plants and animals. They are present in the coal in substantial quantities and exert a strong influence on range ecosystems. Grassland plants have evolved within the constraints of past and present elemental cycles and introduction of excess quantities of these elements could disrupt the plant communities involved. Lead, cadmium, and nickel are known to be highly toxic to animals and are present in the Rosebud coal seam. They were, therefore, selected for detailed study in this investigation.

Mercury, selenium and arsenic are also toxic to plants and animals and are present in the coals to be burned in the power plants; however, because of the extremely small quantities of these elements in most organisms only points of specific elemental accumulation will be analyzed for them. Thus, mercury will be analyzed in aquatic insects and mammalian tissues, selenium in soils and accumulator plants, and arsenic in honey bees.

Beryllium, chromium, and tin are also toxic to plants or animals, but because of their low concentrations in the coal or chemical form required for toxicity they have not been included in this investigation.

Exclosure Study

A second phase of this study has been underway in addition to the determination of baseline soil, vegetation, and animal trace element levels. The four exclosures have been used to establish baseline ecological data as well as trace element concentrations. These exclosures include three common grassland types found in the Colstrip region and one overgrazed site. Biotic factors under study include forage production and quality, plant ground cover, frequency, phenological development and reproduction, species composition, and diversity. Abiotic variables being investigated are monthly precipitation, soil moisture, and air temperature.

Methods

Soil samples were air dried and the 1 mm fraction analyzed for the elements of interest. Soil levels of these elements were determined on diethylenetriamine-pentaacetic acid and five normal nitric acid extracts of surficial materials from each of the collection sites. Five normal nitric acid extraction was used to leach those trace elements from the soils that could possibly be emitted by the stacks at Colstrip in the future, but which would not be chelated by milder extraction techniques. Diethylenetriamine-pentaacetic acid extraction was developed at Colorado State University (6, 7). The DTPA extraction provides a stable complex and a better method for monitoring the availability of micronutrient cations than most traditional extraction techniques in soils such as those found in Eastern Montana.

Soils in exclosures were examined in detail. Two or more pits were dug within each exclosure and samples collected at 10 cm intervals to a depth of 50 cm. This data and the soils themselves are available for future consultation and comparison.

Plant samples were oven dried, ground to pass a 40 mesh screen and analyzed for the appropriate elements. Sulfur concentrations were determined by a modification of the AOAC barium precipitation method (11). Fluoride analysis was by specific ion electrode and heavy metal analyses by atomic absorption spectroscopy.

Large and small game animals have been collected with the cooperation of the State Department of Fish and Game. These animals include deer, antelope, pheasants and grouse. Other animals collected include cottontail rabbits, mice and voles, coyotes, and cattle. Tissues analyzed include femurs, rib, mandible, liver and kidneys.

Lichen studies were to be initiated in the spring of 1974, but another agency funded an investigation similar to ours. We dropped our study to avoid the duplication of effort and useless expense.

Productivity of the grasslands was determined by clipping replicate quadrats within the four exclosures throughout the growing season. Forage quality was defined by analysis of crude protein, total digestible nutrients, carotene, calcium, magnesium, phosphorus, and total caloric energy. Plant cover and frequency were documented following the methods of Daubenmire (4) and recorded by stereophotography. Plant species diversity indices are being developed. They will utilize plant cover data and the procedure of Bonham (1). Soil moisture levels in the exclosures have been determined gravimetrically and with neutron probes. Temperature is monitored by 30 day recording thermographs.

The State Board of Health and the Montana Power Company are independently monitoring ambient air pollutant levels to establish preoperational total sulfur and sulfate, nitrogen oxides, and particulate concentrations. The biological monitoring system of Montana State University is collecting plant tissues near these air monitoring stations and relationships between ambient levels of the more common pollutants and vegetative effects may be derived from the two studies.

RESULTS

Plant Community Studies

Clipping studies indicate that the Colstrip area is far from a desert. Total biomass produced on two rangeland sites averaged over 1000 kg/ha (900 lbs/acre) during 1973 and 1974. Percent bare ground in the same two exclosures was only 8 and 12 percent in 1973 and 13 and 24 percent in 1974.

Frequency and cover of the species present in the four exclosures were indicative of the community type. For example: one exclosure is a *Stipa-Carex* stand. Studies indicated frequency and cover percentages for *Stipa comata* of 94 and 22 percent in 1973 and 96 and 33 percent for 1974. *Carex* species (*Carex eleocharis* and *C. filifolia*) yielded 58 and 9 percent frequency and cover in 1973 and 58 and 8 percent for the same parameters in 1974. Another exclosure showed similar results but for the grass *Agropyron spicatum*. *Stipa comata*, *Koeleria cristata*, *Bouteloua gracilis*, *B. curtipendula*, *Agropyron smithii*, and the *Carex* species were also present in this exclosure, but at decreasing frequencies and cover.

Within these plant communities soil moisture and precipitation has been recorded during the growing season for the past two years. Standard soil analyses as well as trace element analyses have also been completed on these sites. Species lists for each site were compiled in 1973 and 1974, and it is anticipated that they will be compiled again this year. This data, with the diversity index, should provide an objective definition of the diversity of flora within some of the major plant communities of the Colstrip area.

Sulfur

Sulfur levels in grasses from the sampling network around Colstrip averaged less than 0.2 percent during 1972 and 1973. Highest levels were recorded in the spring, a time of maximum physiological activity, and during the fall green up period. Ponderosa pine sulfur levels appeared to be constant throughout the life of the needles and do not reflect the increased sulfur concentrations in older needles characteristically found in areas of sulfur dioxide fumigation.

Fluoride

Carlson used 10 ppm fluoride as a control level for his study of fluoride pollution in the Flathead National Forest (2). Hobbs and Merriman used 8 ppm as the control level in pasture grasses in their study of fluorosis in cattle (10). In this study in and around Colstrip, Montana plant fluoride concentrations averaged less than 8 ppm throughtout the year in all the species investigated. Fluoride levels in grasses ranged from 3 to 6 ppm and forbs were only slightly higher. Ponderosa pine needles averaged between 3.8 and 4.2 ppm for 1970, 1971, and 1972 needles collected in the fall of 1972. This compared favorably with the range of 2-4 ppm given by Miller for Ponderosa pine in unpolluted areas of the state of Washington (12). As with sulfur levels there has been little or no indication of fluoride accumulation in older pine needles.

Cattle fluoride levels in femurs, ribs, and mandibles ranged from a low of 104 ppm in the mandible of a calf to 1000 ppm in the femur of an older range cow. These concentrations were approximately equal to those reported by Hobbs and Merriman for control cows (10). Mule deer and antelope bone fluoride levels were noticeably lower than cattle concentrations. Deer femur fluoride ranged from 50 ppm in a new born fawn to 340 ppm in a buck over eight years old. Antelope fluoride concentrations in femurs ranged from 110 ppm in a two month old animal to 354 ppm in a six year old doe. These differences between wild and domestic animals raise questions which are unanswered to this time.

Trace Metals

Soil concentrations of three of the essential plant nutrients analyzed in our study--iron, manganese, and zinc--were "normal" or near "normal" when compared to Follett and Lindsay's work in Colorado (6). Copper levels were somewhat low, but the plants examined were not displaying any visible copper deficiency syndrome (3. 8). Apparently plant life in the area is absorbing sufficient copper to maintain itself in a healthy physiological state.

A range of 5 to 28 ppm lead was found in acid extracted soils. This dropped to 0.6 to 3.6 ppm lead removed from the soils by the organic chelating agent. Nickel concentrations ranged from 3 to 11 ppm in the soils using the acid extraction technique. Diethylenetriamine-pentaacetic acid extracted nickel ranged from 0.2 to 0.9 ppm. These values appear to be low when compared to soil analyses of other investigators, however direct comparison is difficult because of the variety of techniques used in the study of soil trace elements.

Soils from the 70 study sites yielded values from 0.1 to 0.5 ppm acid extracted cadmium and less than 0.1 ppm DTPA extractable cadmium. Few comparable cadmium analyses exist, however a realistic range for soil cadmium is probably from 0.01 to 1.0 ppm. This study yielded soil analyses well within that range.

Selenium was extracted from the soils in boiling water. The values found by this method ranged from 0.01 to 0.12 ppm. Values in Swaine (14) for water soluble selenium ranged from 0.005 to 8.8 ppm with the vast majority of the samples in the lower part of this range. Study site selenium analyses were indicative of arid western soils.

Trace element levels in plants vary from one species to another. Ecotypic variation and site specific soil availability contribute to variability even between plants of the same species. Thus, trace element levels in plant species, as in soils and animals, exhibit a range of concentrations. This range usually extends from insufficient quantities to abundance. It may be quite wide as with manganese or more narrow as with boron.

Concentrations of zinc and manganese in perennial grasses collected from the study sites were within the ranges quoted by several authors for different grass plants (3, 8). Zinc concentrations ranged from 15 to 40 ppm and manganese from 20 to 60 ppm. The annual Bromes (*Bromus tectorum* and *Bromus japonicus*) yielded higher manganese levels but comparable zinc concentrations. Broad leafed plants generally exhibited higher zinc and manganese levels. Concentrations of these two elements in Ponderosa pine showed a consistency between needles of different ages collected from the same tree but a range of concentrations when trees from different sites were compared.

Threshold concentrations for plant copper deficiency are generally quoted at 3-4 ppm. Average copper concentrations in the grasses of this study were always less than 5 ppm, indicating a low level of Copper in grasses of the Colstrip area. However, the two sagebrushes found in this area rarely yielded less than 10 ppm copper, and analyses usually indicated 15 to 20 ppm in these species.

The toxic elements--lead, cadmium, and nickel--exhibited low plant tissue levels. Analyses have yielded concentrations of 1-2 ppm lead, less than 0.15 ppm cadmium, and approximately 1.0 ppm nickel. These levels are within the rather vague ranges quoted in the literature (3, 13).

CONCLUSIONS

This survey has shown that the rangeland near Colstrip, Montana represents as pollutant free a grassland area as has been described in the United States. Background levels of sulfur, fluoride, and trace elements in plants, animals, and soils indicate little fallout of airborne pollutants. The study has emphasized the properational condition of the range resource to this time, and many analyses remain to be completed, but hopefully with the cooperation of the state, the power company, and ranchers this study will continue.

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DISPERSION FROM AN ELEVATED SOURCE OVER COLSTRIP, MONTANA

James A. Heimbach, Jr., Arlin B. Super, John T. McPartland*

ABSTRACT ONLY**

A diffusion investigation was conducted at Colstrip, Montana, to estimate the effects of the semi-rugged terrain on the dispersion of a plume from an elevated source. The tracing techniques involved the continuous release of silver iodide from an effective height of 500 ft above the general terrain and its subsequent tracking using airborne and ground-based NCAR acoustical ice nucleus counters.

The results show that the additional mechanical turbulence induced by the terrain plays a significant role in the dispersion of contaminants. The horizontal diffusion was larger than predicted by Turner's and Bowne's models at all downwind distances. The vertical diffusion over Colstrip compared favorably to Bowne's urban parameterization and verified his finding that the vertical dispersion approaches a limit for large downwind distances. It was found that the horizontal and vertical diffusion rates were not well correlated. For this reason a dual model is recommended for the area which uses wind speed and lapse rate for predicting vertical diffusion, and wind speed and direction range for the horizontal.

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POSSIBILITIES OF CLIMATE MODIFICATION BY LARGE POWER PLANTS

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INTRODUCTION

The output from a coal-fired electrical power generation plant includes substantial amounts of sensible and latent heat, water vapor, gases and particles. The potential for inadvertent weather modification by this output has not been studied; in a region such as ours, where the precipitation is marginal, and where large scale energy developments are proposed, the potential changes in climate that might result need to be evaluated.

The Department of Atmospheric Science, University of Wyoming, has proposed to study three existing power plants, one each in Wyoming, Montana and North Dakota. These studies will include aircraft and ground observations of the plumes, under a variety of stability, wind shear and topographic conditions. The aim of these investigations will be to assess the potential inadvertent weather modification that may result from continued power plant development in this region.

CLIMATE MODIFICATION BY POWER PLANTS

Power plant plumes have the potential for modifying the local and regional climate by either modifying the energy balance or modifying the cloud microphysics processes. The total energy in a parcel of air is, to a close approximation, the sum of the potential energy, the sensible heat and the latent heat. The sensible heat can be modified by a direct injection of sensible heat or indirectly by radiation processes acting on particulates. The latent heat is increased when water is evaporated and released from cooling towers. The cloud microphysics processes have the possibility of being modified if the power plant plumes contain significant quantities of giant condensation nuclei, cloud condensation nuclei or ice nuclei.

If in the summer season the waste energy and particulates are released into the atmosphere at or near the earth's surface, then they will act to intensify the thermodynamic instability and thereby generate and/or intensify thunderstorms. If sensible heat and/or particulates are injected into the atmosphere at higher levels (1 to 2 km above ground), then the energy profile below the plume will be stable and convection will be suppressed.

In the winter season the vertical gradient of total energy is positive and, hence, the atmosphere is stably stratified. The addition of sensible heat near the surface will produce a heat island while the addition of latent heat will intensify precipitation from stratiform clouds. If the waste energy and particulates are injected aloft, then they will act to intensify inversions.

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Heat and Water Vapor

A typical coal-fired electrical power generation plant is about 40% efficient. The other 60% of the energy is wasted and released into the atmosphere in the form of latent heat (∿50%) and sensible heat (∿10%). A typical coal gasification plant is ∿65% efficient. The wasted energy in this case is released into the atmosphere as latent heat (∿20%) and sensible heat (∿15%).

The gases, particulates and excess sensible heat are released through tall (500 to 1,000 ft) stacks while the excess latent heat is released from cooling towers at the surface. In the winter months when the environment contains strong winds and is stably stratified, the two plumes have very different transport and diffusion characteristics. The differences are because of the strong vertical wind shear present and the rapid damping of the surface induced mechanical turbulence with height. In the summer months when the environment contains light winds and convection is present, the two plumes often merge and rise together. Since many of the chemical reactions which take place in the power plant plume are dependent on water vapor concentration (6), it is important that we understand the conditions when these plumes merge.

Power plants must meet emission and air quality standards. The emission standards limit the tonnage of particulates and certain gases which can be emitted from the stack. By maintaining a high stack exhaust temperature (∿400K) a large amount of the material is emitted as vapor and, hence, is not measured as part of the allowable emission standards even though the vapors condense into particulates shortly after leaving the stack. The air quality standards on the other hand, are monitored by measuring mass concentration of particulates and gases at the surface. By making the stacks tall with hot, high speed exhausts, the plumes are buoyant and rise above the stack a substantial amount even in a very stable environment. The higher the plume rises, the more time it has to disperse in order to meet the air quality standards. Electrostatic precipitators are typically used to remove particulates while scrubbers are used to remove gases like SO_2 and NO_x.

In the past, the waste energy was released into bodies of water but the ecological effects (9) from this form of water pollution caused the energy companies to seek other sinks for the waste energy. For a variety of reasons the atmosphere was selected. A typical environmental impact statement for a proposed power plant usually acknowledges only the expected decrease in air quality and such wet plume phenomenon as fog and icing at the surface. It is rare that an environmental impact statement even considers the possibility of inadvertent climate modification from the waste energy, particulates or gases.

That such a potential for weather modification is present can be seen by comparing the energy released by the power plant with the energy involved in some natural processes. The waste power released by a power plant of 1500 megawatt capacity is equivalent to the solar radiation normally received on a summer day by a 16 km^2 area if the albedo is 0.5. In about four days, the plant releases energy about equal to one thunderstorm. Since natural processes may be triggered by much smaller inputs of energy, especially if concentrated in a small area, the power plants have the potential to cause significant weather changes.

Gases and Particles

The gaseous and particulate emissions of power plants may lead to changes in the structure of clouds, making them either more or less likely to precipitate. In the case of particles, three classes are important:

L. Cloud Condensation Nuclei (CCN's). These particles play a role in determining the initial number and size spectrum of cloud droplets.

2. Giant Nuclei. Condensation on these particles results in large cloud droplets.

3. Ice Nuclei. These particles play a role in the formation of ice in clouds.

Gaseous emissions may play a role in these processes. Through gas-to-particle conversion, the gases may be converted to CCN's in the atmosphere. Also, through surface absorption, the gas may change the characteristics of either CCN's or ice nuclei.

Higher CCN concentrations are generally associated with reduced precipitation probabilities. This is illustrated by the marked difference in the precipitation efficiencies of maritime and continental clouds. The maritime clouds, with low concentrations of CCN's, are more likely to precipitate than are similar continental clouds, with high CCN concentrations. CCN's from air pollution have been observed to modify the structure of clouds toward a more continental character (8, 7). Because the area downwind of the proposed power plants is one of marginal precipitation, any similar modification that leads to reduced precipitation in this region would be serious. At present, the information needed to evaluate the CCN production of large power plants is not available. However, the plant could cause enough particulate emissions to lead to weather modification, and still be within the air quality standards. Dr. R. B. Husar (11) has found that on the order of 5-10% of the sulfur emission from power plants in St. Louis is converted to particles within 20-30 km of the plant, even though initial particulate emission is low in sulfur. Assuming the SO_2 emission standard of 0.14 PPM is met, 10% of 0.14 PPM, if converted to 0.1 μm particles, leads to a concentration of 3,500 particles/cm^3. If a significant fraction of these are CCN's (as is likely for sulfates), there is a possibility of weather modification due to this source.

The particles termed giant nuclei are thought to increase the precipitation probability of clouds. Local sources of giant nuclei have been associated with increases in precipitation (10), but again, measurements relevant to power plants are lacking.

Ice nuclei affect the conversion of a supercooled cloud to ice; they therefore play an important role in the formation of precipitation. Modification of the ice phase by injection of ice nuclei is at present the most common method used for weather modification, and there is evidence (12) that the ice phase is important in the formation of precipitation in this region. Ice nucleus emissions would be likely to increase precipitation, but is is also possible that some of the gaseous emissions would tend to "poison" or render inactive some of the natural ice nuclei, thus decreasing the ice nucleus concentration. In St. Louis, a net decrease in ice nuclei has been found downwind of the urban area (2). However, appropriate measurements regarding power plant emissions have not been made.

In all of these cases, the total emissionsby the plant are large enough that they may have a significant inadvertent weather modification effect. Only a detailed study can assess the nature and possible impact of these emissions. These rough arguments only serve to point out the need for further study. With adequate data, at least a preliminary assessment of the weather modification potential of these plants will be possible.

CURRENT STATE OF KNOWLEDGE

The energy balance has already been upset in a number of areas. In the Thar Desert of India the nomads overgrazed the land on two separate occasions ($\sim$1000 BC and $\sim$1000 AD) and the desert developed (3). The denuded soil allowed dust to blow. The dust acted as a black body aloft and as such absorbed some of the solar radiation (sensible heat) at that level rather than at the earth's surface. Even though quite sufficient moisture was and still is present for rain, the atmosphere is still stabilized and convection is suppressed. The present drought in the Sahel Desert of Africa has a similar story. The United Nations innoculated the nomads and their cows, sheep and goats and they all proliferated. The local governments attempted to stabilize the nomads in order to educate the children. They were congregated around the few water holes and did not move when the grass was gone. The soil was denuded and dust is now quite thick aloft (13). It has been postulated by some that the homesteading of the West during the 1920's accentuated (if not initiated) the Dust Bowl of the 1930's.

Recently Boatman (1) has shown that the precipitation anomaly over and downwind of St. Louis (5) is possibly caused by a deficit in total energy of the air over the city. The summertime deficit in total energy is caused by the deficit in latent heat (evaporation) which is larger than the excess sensible heat (heat island). Consequently, the updrafts in the thunderstorms which move over the city of St. Louis encounter inflow in with less total energy. The updrafts weaken and the accumulated water load in the thunderstorm is dumped over and downwind of the city.

On the other hand, at La Porte, Indiana ($\sim$30 miles east of a large industrial complex at Chicago) Changnon (4) found a notable increase in precipitation, number of rain days, number of thunderstorm days and number of hail days. The increase in severe thunderstorm weather is postulated to be caused by increased total energy from the industrial area.

Nucleation data from large power plant plumes is extremely limited and conflicting. One can say without fear of contradiction that our knowledge in this area is paractically non-existent.

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THE TERRESTRIAL VERTEBRATE FAUNA OF THE ATLANTIC RICHFIELD COMPANY'S BLACK THUNDER COAL LEASE PROPERTY IN CAMPBELL COUNTY, WYOMING

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INTRODUCTION

This report is concerned with baseline information on the terrestrial vertebrate fauna of Atlantic Richfield Company's Black Thunder coal lease property in Campbell County, Wyoming. The Atlantic Richfield Company contracted with the Wyoming Environmental Institute to conduct a comprehensive environmental assessment study of the area which is to be surface-mined for coal. The Institute in turn contracted with the University of Wyoming to obtain baseline information on the physical, biological and social resources of the area. Dr. Oscar H. Paris, Head of the Department of Zoology and Physiology, was appointed Research Coordinator of the research team. My responsibility on the team was to obtain qualitative and quantitative baseline data on the terrestrial vertebrate animals of the area.

The area studied is a federal coal lease block, 6,524 acres in size, located on the east flank of the Powder River Basin, about 40 miles south and 15 miles east of Gillette, Campbell County, Wyoming. Topography of the area is variable from relatively flat areas to parts that are dissected with ravines. Little Thunder Creek extends from west to east across the central part of the area for a distance of about three miles. It is the lowest part of the area and drainages from both the north and south flow into it. There is no permanent stream flow but seepages along the stream bed form intermittent pools. A dam has been built across the western part of the creek and water is impounded behind it for a distance of about a half mile.

METHODS

On-site studies were begun March 2, 1974 and extended through August 10. Four observation routes were established in early March with observation stations spaced at intervals of approximately one kilometer (0.6 mile) along each route (Figure 1). Each time that the routes were traversed a three to five minute stop was made at each observation station where the kinds and numbers of vertebrates seen and heard were recorded. The numbers of times each route was traversed between March 3 and August 9, varied from 14 to 17.

Rodents were trapped with snap traps along 42 transects distributed in eight different habitat types within the area (Table I). The number of transects per habitat type varied from three to seven. Each transect was 285 meters (935 feet) long with 20 trapping stations spaced at 15-meter (49-foot) intervals. Two Museum Special traps were set at each station. Each transect was trapped for two 24-hour periods. Transect trapping was done from March 30 to August 10.

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Six live-trapping plots were established and each was trapped two to three times with each trapping period being two to three days in length. Each plot was square with each side being 90 meters (295 feet) long. Each enclosed an area of 0.81 hectares (2 acres). Forty-nine trapping stations, marked with stakes, were spaced at 15-meter (49-foot) intervals within each plot. Two Sherman live traps, 7.5 x 7.5 x 25 centimeters in size, were set within a five to six foot radius of each stake. Each trap was numbered and the same numbered traps were set at the same trapping stations each time that the plot was trapped. Each trap was checked three times a day. The plots were trapped in pairs with one member of each pair, A, C and F, being in a sagebrush-grass area, and B, D, and E being in a grass-opuntia area. There was a small amount of sagebrush in plot E. Each captured animal was marked for future identification by clipping one or two of its toes.

The same plots that were used for live-trapping purposes were also used to obtain information on the abundance of rabbits and certain passerine birds. Each plot was censused four to eight times during the summer by traversing on foot the 15-meter lines and recording the numbers and kinds of birds and rabbits seen. General observations were made throughout the area for evidence of the presence of all types of vertebrates.

RESULTS

Mammals

Twenty-one species of mammals representing eight families were encountered in the area. The rodents were represented by eleven species that belonged to four families. Other mammals included three species of rabbits, three species of mustelids, two members of the deer family, and the pronghorn, Antilocapridae.

A total of 439 rodents of nine species were captured along the 42 transects (Table I). The numbers captured per transect varied from zero in two transects to a maximum of 28 with an average of 10.45 for the 42 transects. The number of species per transect varied from zero to four.

Whereas nine different species of rodents were captured along the 42 transects in eight different habitat types, six different species were captured in the six live-trapping plots that were located in only two major habitat or community types. The deer mouse (*Peromyscus maniculatus*), the thirteen-lined ground squirrel (*Spermophilus tridecemliniatus*) and the grasshopper mouse (*Onychomys leucogaster*) were captured in all six live-traping plots. The pocket mouse (*Perognathus fasciatus*) was taken in only two plots while the kangaroo rat (*Dipodomys ordii*) and the bushy-tailed wood rat (*Neotoma cinerea*) were each taken in different single plots. Species that were captured along the transects but which were not captured in the live-trapping plots included the prairie vole (*Microtus ochrogaster*), the harvest mouse (*Reithrodontomys megalotis*), the sagebrush vole (*Lagurus curtatus*) and a juvenile pocket gopher (*Thomomys talpoides*). The bushy-tailed wood rat was the only species captured in the live-trapping plots that was not captured along the transects.

Population densities of captured rodents within the live-trapping plots varied from 27 to 35 with an average of 30.42

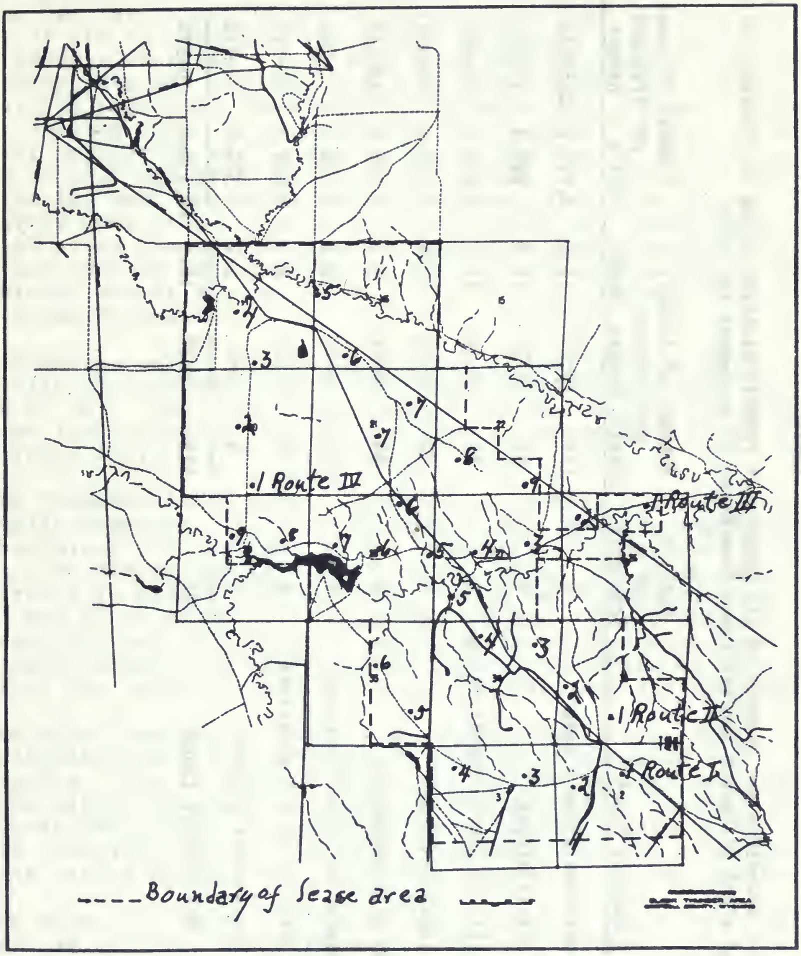

Figure 1. Locations of Observation Routes (I, II, III, and IV) with numbered Observation Stations along each route.

Table I

Relative abundance and biomass of all species of rodents captured along 42 transects within each of eight different habitat types from March 31 to August 10, 1974.

Habitat Types	Numbers of Transects	Numbers of Animals per transect			Biomass in grams per transect		
		Totals	Ranges	Means	Totals	Ranges	Means
Rocky outcrops along ridges	6	110	12-28	18.3	2,276.9	265-576	379.5
Flat, grassy playas	4	46	5-14	11.5	829.3	97-271	207.3
Floodplain of Little Thunder Creek	5	56	2-20	11.2	1,642.0	45-548	328.4
Flat, sagebrush areas	5	52	7-13	10.4	1,249.2	168-361	249.8
Ravines with sagebrush	7	64	4-14	9.1	1,535.5	139-334	219.4
Revegetated oil pipeline areas	6	52	0-16	8.7	1,296.5	0-380	216.1
Areas parallel to oil pipelines	6	50	3-20	8.3	1,027.3	67-374	171.2
Flat, grass-opuntia areas	3	9	0-6	3.0	377.7	0-279	125.9
All habitat types	42	439	0-28	10.5	10,234.4	0-576	243.7

for the six plots (Table IIIa). When the populations are computed on the basis of number of rodents per hectare (2.47 acres) they range from 33.3 to 43.2 with an average of 37.6 (Table IIIb). Since there was probably some ingress of animals from areas that bordered each plot these population densities may be somewhat high.

The *Peromyscus* or deer mouse was found to be the most abundant and widely distributed of all the rodents. This species was captured in all the live-trapping plots, in all of the eight types of habitats where transect trapping was done and in all but two of the 42 transects where they comprised 84.51 percent of the rodents captured. They were most abundant along ridges where rocky outcrops occurred and where the predominant vegetation was big sagebrush (*Artemesia tridentata*) and grasses. Within this habitat type they constituted 95.4 percent of the captured rodent population and varied in number from 10 to 28 with an average of 17.3 per transect for six transects.(Table IV). They were also the most prevalent rodent captured along the grassy playa areas where they made up 97.8 percent of the rodents captured and along the ravines where big sagebrush predominated and where they made up 96.9 percent of the captured rodent population. The captured rodent population of all 42 transects consisted of 84.4 percent *Peromyscus*.

Peromyscus were captured in all six of the live trapping plots while their numbers per plot varied from 5 to 25 with an average of 14.5 They were most abundant in the sagebrush-grass plots and least abundant in the more open grass-opuntia plots B and D (Table III).

The thirteen-lined ground squirrel was widely distributed and locally abundant. It was captured in all the live-trapping plots and along 40.5 percent of the transects. It was more abundant than *Peromyscus* in plots A, B and D and varied in abundance from 4 in plot F to 27 in plot D with an average of 13.8 for all six plots (Table III). In plots B and D these animals comprised 75.0 and 77.1 percent respectively of the total captured rodent population in these two plots. They made up 55.5 percent of the rodents captured along the grass-opuntia transects.

The other species of rodents are much more restricted in their distribution and less abundant than are *Peromyscus* and *Spermophilus*. The 19 prairie voles and the two harvest mice were all taken along transects in meadow-like flood plain habitats along Little Thunder Creek. The harvest mice were captured in separate transects and the prairie voles were taken in all five transects with a maximum of six being captured along one transect.

The sagebrush vole is evidently very scarce. Only six were captured, in six different transects. All were taken along transects where sagebrush occurred. None was captured in the live-trapping plots.

Grasshopper mice were captured in all six live-trapping plots within which their numbers varied from one to two per plot (Table III). Only three were captured along the 42 transects for a frequency of only 7.1 percent. This species may be more abundant than the trapping results indicate. Because it is carnivorous it may not be as susceptible to capture as granivorous species

Table II

Relative abundance, biomass and frequencies of occurrence of rodent species captured during 3,320 trap-nights along 42 transects from March 31 to August 10, 1974.

	Number of Captures			Biomass (Grams)		
Species	Total	Means Per Transect	Ranges Per Transect	Total	Means Per Transect	Percent Frequency
Peromyscus maniculatus	371	8.83	0-28	7,032.3	167.4	95.24
Spermophilus tridecemlineatus	31	0.74	0-4	1,892.2	45.0	40.48
Microtus ochrogaster	19	0.45	0-6	735.9	17.5	11.90
Lagurus curtatus	6	0.14	0-1	159.9	3.8	14.28
Dipodomys ordii	5	0.12	0-1	216.8	5.2	11.90
Onychomys leucogaster	3	0.07	0-1	95.5	2.3	7.14
Reithrodontomys megalotis	2	0.05	0-1	24.7	0.6	4.76
Thomomys talpoides	1	0.02	0-1	66.7	1.6	2.38
Perognathus fasciatus	1	0.02	0-1	10.4	0.2	2.38
All species	439	10.45	0-28	10,234.4	243.7	95.24

Table III

Population densities within live-trapping plots.

	A	B	C	D	E	F	Totals	Means
a. Numbers captured per plot (0.81 hectares).								
Peromyscus maniculatus	11	5	17	5	24	25	87	14.5
Spermophilus tridecemlineatus	15	21	8	27	8	4	83	13.8
Onychomys leucogaster	1	2	1	2	2	1	9	1.5
Perognathus fasciatus	0	0	0	1	1	0	2	0.3
Dipodomys ordii	0	0	1	0	0	0	1	0.16
Neotoma cinerea	0	0	0	0	0	1	1	0.16
Totals	27	28	27	35	35	31	183	30.42
b. Numbers per hectare within plots 90x90 meters (0.81 hectares).								
Peromyscus maniculatus	13.6	6.2	21.0	6.2	29.6	30.9	107.5	17.9
Spermophilus tridecemlineatus	18.5	25.9	9.9	33.3	9.9	4.9	102.4	17.0
Onychomys leucogaster	1.2	2.5	1.2	2.5	2.5	1.2	11.1	1.9
Perognathus fasciatus	0	0	0	1.2	1.2	0	2.4	0.4
Dipodomys ordii	0	0	1.2	0	0	0	1.2	0.2
Neotoma cinerea	0	0	0	0	0	0	1.2	0.2
Totals	33.3	34.6	33.3	43.2	43.2	38.2	225.8	37.6
c. Numbers per hectare if a periphery area of 15 meters is included, which increase the plot size to 1.44 hectares.								
Peromyscus maniculatus	7.6	3.5	11.8	3.5	16.7	17.4	61.5	10.25
Spermophilus tridecemlineatus	10.4	14.6	5.5	18.7	5.5	2.8	57.5	9.58
Onychomys leucogaster	0.7	1.4	0.7	1.4	1.4	0.7	6.3	1.05
Perognathus fasciatus	0	0	0	0.7	0.7	0	1.4	0.23
Dipodomys ordii	0	0	0.7	0	0	0	0.7	0.12
Neotoma cinerea	0	0	0					
Totals	18.7	19.5	18.7	24.3	24.3	21.6	128.1	21.35

Table IV

Relative abundance and biomass of the deer mouse, *Peromyscus maniculatus*, as determined by transect trapping within eight different habitat types.

Habitat Types	Numbers of Transects	Numbers Captured per transect Total	Range	Mean	Biomass in Grams per transect Total	Range	Mean
Rocky outcrops along ridges	6	105	10-28	17.3	2,047	158-586	341.2
Flat, grassy playas	4	45	5-14	11.2	769	97-206	192.3
Ravines with sagebrush	7	62	3-14	8.9	1,410	73-335	201.5
Flat, sagebrush areas	5	44	7-11	8.8	888	113-267	177.5
Areas parallel with oil pipelines	6	41	2-17	6.8	690	36-250	115.0
Along revegetated oil pipelines	6	40	0-13	6.7	672	0-255	112.0
Floodplain of Little Thunder Creek	5	30	1-14	6.0	498	20-218	99.6
Flat, grass-opuntia areas	3	4	0- 2	1.3	67	0- 35	22.4
All habitat types	42	371	0-28	8.8	7,041	0-586	167.6

because of the oatmeal that was used as bait.

The two species of heteromyids, Ord's kangaroo rat and the olive-backed pocket mouse were found to be scarce. Only one kangaroo rat and two pocket mice were captured in three of the plots. Five kangaroo rats and only one pocket mouse were captured along the 42 transects, with four of the kangaroo rats being taken along transects located on revegetated oil pipeline rights-of-way.

One bushy-tailed wood rat was captured in live-trapping plot F. This plot was located in a flat sagebrush-grass area unlike the rocky outcrops and cliffs where this species usually occurs and where the only other evidence of its presence was found.

Two species of jack rabbits, the white-tailed jack rabbit (*Lepus townsendii*) and the black-tailed jack rabit (*Lepus californicus*) occur in the area. Whereas the white-tails were commonly seen throughout most of the area, the black-tail was seen in only one particular part of the area. The number of white-tails varied from zero in plot B, a grass-opuntia plot, to 1.23 per hectare with an average of 0.89 for all six plots (Table Va).

Cottontail rabbits (*Sylvilagus audubonii*) were distributed throughout the area being most commonly encountered along ridges where rocky outcrops, old badger holes and sagebrush provided them with places of refuge and protection. Mean cottontail populations varied from zero in three of the plots to as much as 3.29 per hectare in one plot with an average of 0.76 for all plots (Table Vb).

The abundance of all species of rabbits ranged from zero to 4.5 per hectare with an average of 1.68 for all six plots. Within the sagebrush-grass plots the rabbit population varied from 0.5 to 7.4 per hectare with an average of 2.2, while in the grass-opuntia plots the populations varied from zero to 2.5 with an average of 0.62 per hectare (Table Vc). Although both jack rabbits and cottontails were widely distributed, the jack rabbits were most abundant where there was good sagebrush cover, although some occurred in the more open areas where they utilized old badger burrows as places of refuge.

Three species of mustelids, the badger (*Taxidea taxus*), the long-tailed weasel (*Mustela frenata*) and the striped skunk (*Mephitis mephitis*) were encountered in the area. Although only two badgers were seen, evidence of their presence in the form of new diggings for ground squirrels and pocket gophers and their old burrows were prevalent throughout the area.

Mule deer (*Odocoileus hemionus*) were seen on numerous occasions in areas of broken topography along ravines south of Little Thunder Creek. Adults of both sexes as well as fauns were seen. Groups of three to as many as 15 were observed during the study period.

A herd of 21 wapiti or American elk (*Cervus canadensis*) were seen August 9 along Little Thunder Creek. This herd consisted of eight cows, eight calves and five spike bulls.

Table V

Frequency and abundance of rabbits within six live-trapping plots from May 11 to August 8, 1974.

Plots	Number per Hectare		Percent
Designation and Vegetation types	Range	Average	Frequency
a. White-tailed Jack Rabbits			
A. Sagebrush-grass	0-1.65	0.71	71.43
B. Grass-opuntia	0.0	0.00	0.00
C. Sagebrush-grass	0-1.23	0.93	75.00
D. Grass-opuntia	0-2.47	1.23	75.00
E. Grass-sagebrush	1.23	1.23	100.00
F. Sagebrush-grass	1.23	1.23	100.00
All six plots	0-2.47	0.89	70.24
Plots A, C, E and F	0-1.23	1.02	86.61
Plots B and D	0-2.47	0.66	37.50
b. Cottontail Rabbits			
A. Sagebrush-grass	0-1.65	0.63	71.43
B. Grass-opuntia	0	0.00	0.00
C. Sagebrush-grass	0-1.23	0.62	50.00
D. Grass-opuntia	0	0.00	0.00
E. Grass-sagebrush	0	0.00	0.00
F. Sagebrush-grass	1.23-6.17	3.29	100.00
All six plots	0-6.17	0.76	36.90
Plots A, C, E and F	0-6.17	1.14	55.36
Plots B and D	0	0.00	0.00
c. All Rabbit Species*			
A. Sagebrush-grass	0.55-2.75*	1.57*	100.00
B. Grass-opuntia	0	0.00	0.00
C. Sagebrush-grass	1.23-2.47	1.55	100.00
D. Grass-opuntia	0-2.47	1.23	75.00
E. Grass-sagebrush	1.23	1.23	100.00
F. Sagebrush-grass	2.47-7.41	4.52	100.00
All six plots	0-7.41	1.68*	79.17
Plots A, C, E and F	0.55-7.41	2.21*	100.00
Plots B and D	0-2.47	0.62	37.50

* Includes one black-tailed jack rabbit.

The American pronghorn (*Antilocapra americana*) is a year-around resident of the area. The pronghorns are widely distributed and unlike the deer they move freely throughout the area as well as in and out of it. A summary of pronghorn sightings from March 10 to August 9, 1974 along the four observation routes is presented in Table VI. The greatest total mean numbers occurred along Route 1 which ran sout-east to north-west near the southern end of the lease area. This was the shortest of all the routes with only six observation stations along it but the average number of pronghorns seen per traverse along it was 20.7 compared to 16.2 for the other routes. The average number sighted per observation station was also greatest along Route I. The frequency of occurrence per traverse was 100 percent along routes I and III while it was 89.25 percent for the other two routes. The number of adult pronghorns that regularly occurred in the area, based on sightings along the four observation routes, is estimated to be between 60 and 80.

Birds

A total of 67 species of birds were recorded for the area during the period from December 11, 1973 to August 9, 1974. These included 15 species of ducks and geese together with grebes, mergansers, coots, wading and shore birds. Ten species of birds of prey occurred in the area as well as a wide variety of passerine birds of which the Horned Lark (*Eremophila alpestris*) was the most numerous and widely distributed species.

The Sage Grouse (*Centrocercus urophasianus*) was the only upland game bird species found to be present. This species was most commonly seen after the nesting season.

Six species of birds of prey were seen along the four observation routes with the greatest number of individuals occurring along Route III which parallels Little Thunder Creek and the reservoir (Table VII). The average number seen per traverse ranged from 0.5 along Route IV to 2.4 along Route III. The four species that were seen in the greatest numbers and with the greatest frequency were the Golden Eagle (*Aquila chrysaetos*), the Red tailed Hawk (*Buteo jamaicensis*), the Marsh Hawk (*Circus cyaneus*), and the Ferruginous Hawk (*Buteo regalis*). Two pairs of Red-tailed Hawks, at least one pair of American Kestrels (*Falco sparverius*), and a pair of Great Horned Owls (*Bubo virginianus*) nested in the cottonwood trees along Little Thunder Creek.

The three most common species of passerine birds encountered along the four observation routes were the Horned Lark, the Western Meadowlark (*Sturnella neglecta*) and the Lark Bunting (*Calamospiza melanocorys*) (Table VIII).

The most characteristic birds that occurred within the study plots were the Brewer's Sparrow (*Spizella breweri*), the Vesper Sparrow (*Pooecetes gramineus*), the Horned Lark and the Lark Bunting. As a result of each plot being censused four to eight times during the period from May 11 to August 9, it was found that the Brewer's Sparrow and the Vesper Sparrow occurred in the four plots where some sagebrush was present but never occurred in the grass-opuntia plots, B and D. Brewer's Sparrow numbers varied from zero to 2.75 per hectare with a mean of 0.58 for all six plots and a mean of 0.88 for plots A, C, E and F in which sagebrush occurred

Table VI

Summary of sightings of American pronghorn, Antilocapra americana, along the four observation routes and 31 observation stations.

Observation Routes	I	II	III	IV	All four
Time periods during which routes were traversed	3-12 to 8-8	3-3 to 8-6	3-3 to 8-9	3-12 to 8-9	3-3 to 8-9
Number of times routes were traversed	17	17	16	14	14 to 17
Numbers of pronghorns sighted (Total)	352	193	218	277	1040
Numbers per traverse					
Ranges	1-45	0-40	0-55	3-41	0-55
Averages	20.7	11.3	13.6	19.8	16.2
Percent frequency of occurrence	100	88.2	68.7	100	89.2
Numbers per station					
Maximum	29	27	41	27	41
Average	3.4	1.3	1.5	2.2	2.1
Percent frequency of occurrence	35.3	17.0	13.2	31.7	24.6

Table VII

Relative abundance and frequencies of occurrence of birds of prey at observation stations along four observation routes during the period from March 3 to August 9, 1974.

Observation Routes	I	II	III	IV
Periods of Time	3/12-8/8	3/13-8/6	3/3-8/9	3/12-8/9
Number of Times Routes were traversed	17	15	18	15
Total Numbers of each species observed for all traverses:				
Golden Eagle	10	4	17	3
Ferruginous Hawk	2	6	11	2
Red-tailed Hawk	0	2	14	0
Marsh Hawk	2	1	0	3
American Kestrel	1	0	0	0
Unidentified hawk	1	1	1	0
Great Horned Owl	0	1	1	0
All species	16	15	44	8
All species				
Numbers per traverse				
Ranges	0-3	0-3	0-7	0-3
Averages	0.94	1.0	2.44	0.53
Frequences of occurrence (percent)	76.47	60.00	77.78	33.33
Numbers per station				
Maximum	2	2	4	2
Averages	0.16	0.15	0.29	0.07
Frequencies of occurrence (percent)	17.65	13.13	20.0	5.93

Table VIII

Comparative frequencies and relative abundances of Horned Lark, Western Meadowlark and Lark Bunting at observation stations along four observation routes during the period from March 30* to August 9, 1974.

Species of Birds	Horned Lark	Meadowlark	Lark Bunting
Number of Times routes were traversed	54	53	37
Numbers of birds seen and heard..Total	306	143	105
Per Route			
Ranges	50-105	24-52	7-44
Averages	53.0	35.5	26.2
Per Traverse			
Extremes	0-21	0-11	0-23
Ranges of averages	3.8-8.7	1.7-3.7	0.9-4.4
Averages for all traverses	5.7	2.7	2.8
Frequences of occurrence (percent)			
Ranges per route	92.3-100	64.3-84.6	40.0-88.9
Averages for all routes	98.2	75.6	59.5
Per Observation Station			
Maximum numbers			
Range per route	4-6	2-5	2-23
Average all routes	6.0	3.5	8.7
Average numbers			
Range per route	0.6-1.1	0.3-0.4	0.1-0.4
Averages for all routes	0.81	0.36	0.39
Frequencies of occurrence (percent)			
Range per route	37.4-60.4	22.0-34.4	7.50-35.2
Averages for all routes	42.9	28.1	17.2

*Lark Bunting data from May 11 to August 9, 1974.

(Table IX). The Vesper Sparrow varied in abundance from zero to 2.47 per hectare with means of 0.22 for all plots and 0.35 for the four plots in which sagebrush occurred. (Table IX).

The Horned Lark occurred in only three of the six plots. It varied in abundance from zero to 3.7 per hectare with a mean of only 0.19 per hectare in those plots with sagebrush compared to means of 0.61 for the grass-opuntia plots and 0.33 for all plots (Table IX).

The Lark Bunting occurred in four of the plots and attained a maximum mean density of 0.57 per hectare for the sagebrush plots, 0.20 for the grass-opuntia plots and 0.45 for all six plots. The abundance of all four species of birds ranged from zero to 3.7 per hectare with a maximum mean of 2.88 for plot F and a mean of 1.59 per hectare for all plots.

Evidence of nesting was obtained for 16 species of birds and another 10 species were suspected of nesting within the area (Table X).

Terrestrial Cold-blooded Vertebrates

Four species of reptiles and two species of amphibians were encountered during the study. The reptiles included the eastern shorthorned lizard (*Phrynosoma douglassi*), the common bull snake (*Pituophis catenifer*), the wandering garter snake (*Thamnophis ordinoides*) and the prairie rattlesnake (*Crotalus viridis*).

The amphibians encountered were the Western Swamp Cricket frog (*Pseudacris nigrita*) and the Leopard frog (*Rana pipiens*). Both species were restricted to the areas bordering pools of standing water along Little Thunder Creek and in certain places along the water's edge of the reservoir.

Table IX

Comparative population densities and frequencies of four species of passerine birds on six study plots.

Species	Total Number Seen	Number Per Hectare Range	Number Per Hectare Average	Percent Frequencies of occurrence Plots	Percent Frequencies of occurrence Censuses
a. All six plots					
Brewer's Sparrow	26	0-2.75	0.58	66.67	40.54
Vesper Sparrow	8	0-2.47	0.23	33.33	16.22
Horned Lark	14	0-3.70	0.33	50.00	21.62
Lark Bunting	15	0-2.47	0.45	66.67	32.43
All four species	63	0-3.70	1.59	83.33*	70.27*
b. Plots A, C, E and F. All with some sagebrush present.					
Brewer's Sparrow	26	0-2.75	0.88	100.0	55.56
Vesper Sparrow	8	0-2.47	0.35	50.0	22.22
Horned Lark	8	0-2.75	0.19	50.0	14.81
Lark Bunting	13	0-2.47	0.57	75.0	37.04
All four species	55	0-2.75	1.99	68.75*	32.41*
c. Plots B and D. Predominately grasses and opuntia.					
Brewer's Sparrow	0	0	0.00	0.00	0.00
Vesper Sparrow	0	0	0.00	0.00	0.00
Horned Lark	6	0-3.70	0.61	50.00	40.00
Lark Bunting	2	0-1.23	0.20	50.00	27.00
All four species	8	0-3.70	0.81	25.00*	16.75*

* Based on one or more species being present.

TABLE X

Known Nesting Species of Birds, ARCo Black Thunder Coal Lease Area, Campbell County, Wyoming, 1974.

Mallard	Anas platyrhynchos
Red-tailed Hawk	Buteo jamaicensis
American Kestrel	Falco sparverius
Sage Grouse	Centrocercus urophasianus
Killdeer	Charadrius vociferus
Great Horned Owl	Bubo virginianus
Short-eared Owl	Asio flammeus
Common Flicker	Colaptes auratus
Say's Phoebe	Sayornis saya
Horned Lark	Eremophila alpestris
Cliff Swallow	Petrochelidon pyrohonota
Western Meadowlark	Sturnella neglecta
Red-winged Blackbird	Agelaius phoeniceus
Lark Bunting	Calamospiza melanocorys
Vesper Sparrow	Pooecetes gramineus
Brewer's Sparrow	Spizella breweri

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SURFACE RESOURCE INVENTORY OF EASTERN MONTANA RANGELANDS UTILIZING HIGH ALTITUDE COLOR INFRARED AERIAL PHOTOGRAPHY

Fred T. Batson & Joe C. Elliott*

INTRODUCTION

Strippable coal deposits in the Fort Union formation encompass lands in Montana, Wyoming, North and South Dakota and the Province of Saskatchewan. Best estimates place the amount of these strippable reserves at 83 billion tons (6). In eastern Montana alone it is estimated that 42 billion tons of strippable coal exists (3). The surface values associated with these deposits are varied and complex. Comprehensive surface resource data of the quality necessary to allow Federal and State agencies to plan properly exists only on small areas. In order to permit responsible agencies to fully assess the possible environmental impacts associated with development of the coal reserves, large surface areas must be accurately inventoried and monitored. Currently available remote sensing techniques can provide data on vegetative resources, watershed conditions, surface hydrology, potential wildlife habitat, current land uses, and other important surface values. Since 1972, the Bureau of Land Management (BLM), U.S. Department of the Interior, has inventoried nearly 3 million acres of land overlaying strippable coal reserves in southeastern Montana using small scale color infrared aerial photography. It is the best inventory tool available and will serve as baseline data from which to assess the actual impacts of various kinds of coal development.

DESCRIPTION OF INVENTORY AREAS

Two planning units totaling 3,000 square miles, were inventoried with 1:80,000 scale color infrared aerial photography during 1974. Their locations are shown in Figure 1.

South Rosebud Unit

The South Rosebud Unit is bounded by the Yellowstone River on the north, the Tongue River on the east, and the Northern Cheyenne Reservation on the south. The dominant land uses are livestock grazing and crop production. The unit consists of 1,028,165 surface acres of which 90 percent is under private ownership, 5 percent is State owned and 5 percent is Federally owned. As is the case in many areas, although most of the surface is privately owned, most of the subsurface mineral estate belongs to the Federal Government. In this unit, 51 percent of the strippable coal reserves are Federally owned. The Bureau of Land Management has the responsibility for leasing Federal mineral rights. This private surface/Federal coal situation further emphasizes the absolute necessity for comprehensive surface inventories so that all values can be considered during the

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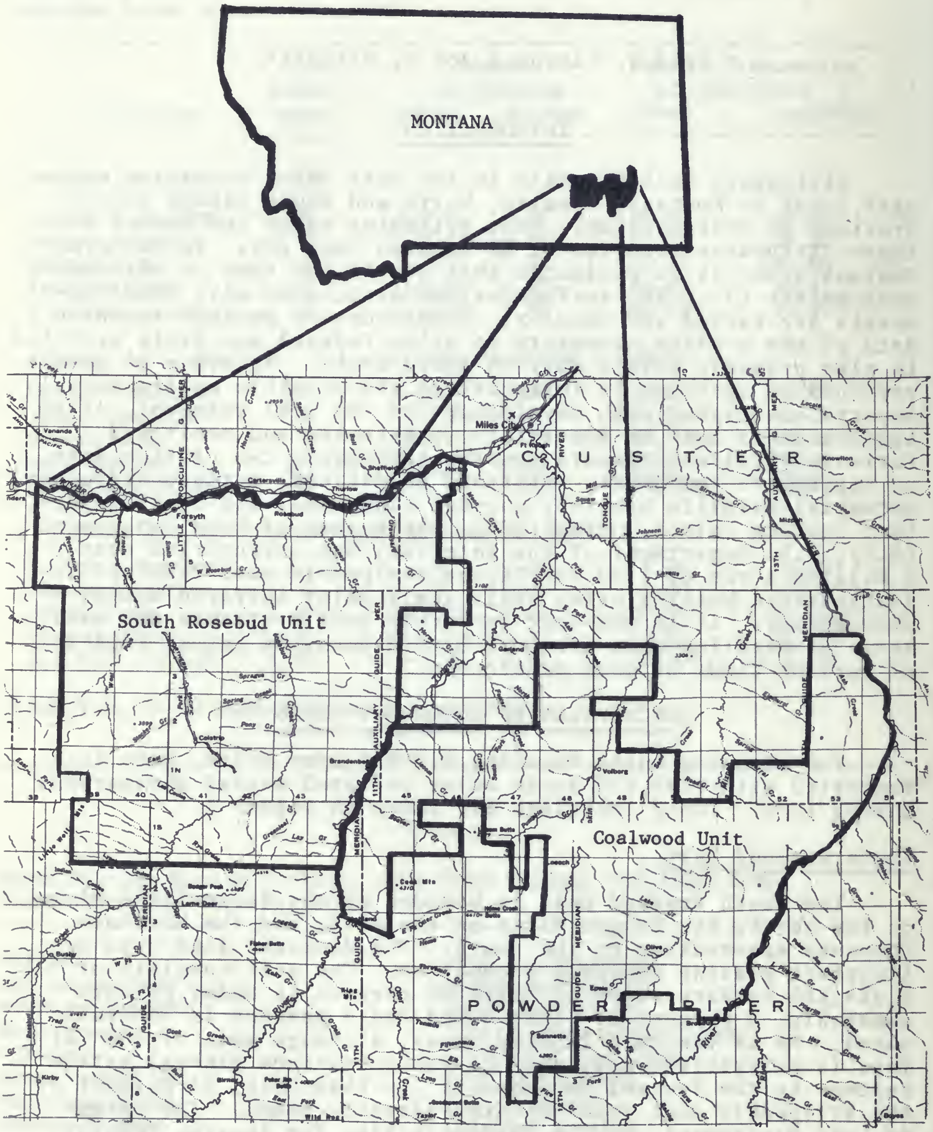

Figure 1 - South Rosebud and Coalwood Units with location map

planning process.

Two active strip mining operations are located in the South Rosebud Unit. These operations taken together will mine 8 million tons during 1975, with plans to mine 22 million tons per year by 1980 (5). In addition, two coal fired power generation facilities, each capable of generating 330 MW of electricity are currently under construction within the unit at the town of Colstrip (5).

Coalwood Unit

The second inventory area, the Coalwood Unit, is located to the southeast of the South Rosebud area. It is bounded by the Powder River on the east and southeast, and the Tongue River and Ashland Division of the Custer National Forest on the west. Livestock grazing and crop production are the dominant land uses. Although there are vast coal reserves in the unit, no coal mining or power generation operations exist at the present time.

The Coalwood Unit consists of 916,933 surface acres of which 90 percent is under private ownership, 6 percent is State owned and 4 percent is Federally owned. Forty-nine percent (49%) of the strippable coal reserves are Federally owned.

STUDY DEVELOPMENT

South of the Rosebud Unit and west of the Coalwood Unit lies the Decker-Birney Planning Unit. A surface resource inventory based on 1:40,000 scale color infrared photography was completed in 1972. Two BLM personnel completed the photo interpretation and mapping for this one million acre unit in one and one-half months (2).

Based on the success of this pilot study, the Montana State Office and the Miles City District Office of the BLM embarked on a similar project on two additional units (South Rosebud and Coalwood) during the summer and fall of 1974. A photo-based inventory was determined to be the most rapid, reliable, and economical method for gathering the required data.

Aerial Photography

It was decided that 1:80,000 scale quad-centered color infrared aerial photography would be the basis for the inventory. Our experience in Montana indicated that the unique properties of color infrared film exposed at vegetative "peak-of-green" would significantly simplify interpretation of important resource features (1, 2, 4).

We specified the 1:80,000 scale because we could obtain quad-centered images from which photo quads could be produced. This would be accomplished by centering every other photo along a flight line precisely at the center point of a USGS 7½ minute quad. Negatives of these quad-centered photos could then be enlarged, rectified, trimmed, and labelled, producing full-sized transparent photo quads. These transparencies can then be run through an Ozelid or Bruning machine to produce inexpensive paper copies for field use.

On June 28, 1974, both units (3,000 square miles) were photographed with 9 inch x 9 inch format color infrared film (Aerochrome 2443) at 1:80,000 scale. A jet aircraft was used for the photography since our specifications (1:80,000 scale - 6 inch focal length) necessitated an aircraft altitude of 40,000 feet above ground datum.

In addition to the color infrared transparencies and black and white inter-negatives, black and white contact prints were also specified. These contact prints were essential in establishing effective areas on the photos for interpretation and mapping and also in field checking the interpreted overlays since the 9 inch x 9 inch color infrared transparencies are not a field tool.

Interpretation

Two approaches to interpretation were considered. A multidisciplinary team of BLM specialists (range, watershed, wildlife, geology) could be formed to do the job. The advantages to this approach would be to assure that the data would be in the proper format and intensity so that it would fit the needs of the BLM planning system. The second approach would consist of contracting the interpretive services to an outside firm. This would entail development of a comprehensive contract with tight specifications to assure a high quality product.

Due to prior commitments of BLM personnel, it was decided that the interpretation could not be accomplished in a timely fashion "in-house." Therefore, development of the interpretation contract was initiated. To assure that a high quality produce was produced, the BLM requested that technical proposals be submitted by interested firms. After evaluation of these technical proposals, those judged to be acceptable were invited to bid on the contract. Both aerial photography and interpretation were included in the same contract. The contractor started the interpretation only after formal acceptance of the required photography by the BLM.

INTERPRETATION OF RESOURCE INFORMATION

The techniques used during the interpretation and mapping phases of the project were similar to those described by Cosgriffe, Linne, and Meyer (2). Resource features were delineated on clear transparent 9 inch x 9 inch overlays placed over the CIR photography on a photographic light table. A scanning stereoscope with 1½-9 power magnification capability was the primary interpretation tool.

The resource data recorded on the clear overlays was transferred to a base map scale of 1:126,720 with the aid of a reflecting projector. A minimum of three control points were selected that were common to the aerial photography, the overlays and the base map. It was necessary during the transfer process to change the scale of the overlays (1:80,000) to coincide with the scale of the base map (1:126,720). This was done by making the proper adjustments on the reflecting projector.

The following features were interpreted from the aerial photography: vegetative types, current land use, present erosion condition, erosion susceptibility, surface hydrology, porcellanite, rangeland utilization, and potential wildlife habitat.

DESCRIPTION OF EACH OF THE OVERLAYS

Vegetative Types

Several small scale vegetation maps (1:1,000,000) of eastern Montana have been constructed which delineate general vegetational characteristics. There have, however, been a few vegetation maps produced that are of relatively large scale and yet cover fairly extensive land areas. Color infrared aerial photography, used in conjunction with ground reconnaissance and a review of existing literature, produced vegetative maps at ½ inch per mile for both the South Rosebud and Coalwood Units. The following vegetative types were identified:

Grassland Types

1. Western wheatgrass/Junegrass/Cheatgrass/Sandberg bluegrass (*Agropyron smithii*/*Koeleria cristata*/*Bromus tectorum*/*Poa secunda*) community.

2. Needle-and-thread/Western wheatgrass/Blue grama (*Stipa comata*/*Agropyron smithii*/*Bouteloua gracilis*) community.

3. Cheatgrass (*Bromus tectorum*) type.

4. Sweetclover (*Melilotus* spp.)type.

Note: The Cheatgrass and Sweetclover types were indicative of recently disturbed areas.

Shrub Types

1. Silver sagebrush (*Artemisia cana*)/grassland community.

2. Big sagebrush (*Artemisia tridentata*)/grassland community.

3. Skunkbrush sumac/Bluebunch wheatgrass (*Rhus trilobata*/*Agropyron spicatum*) community.

4. Skunkbrush sumac/Needle-and-thread (*Rhus trilobata*/*Stipa comata*) community.

5. Snowberry/Prairie rose (*Symphoricarpos* spp./*Rosa arkansana*) community.

6. Greasewood (*Sarcobatus vermiculatus*) type.

Tree Types

1. Ponderosa pine/Bluebunch wheatgrass/Sideoats grama (*Pinus ponderosa*/*Agropyron spicatum*/*Bouteloua curtipendula*) community.

2. Ponderosa pine/Western wheatgrass (*Pinus ponderosa/Agropyron smithii*) community.

3. Ponderosa pine/Rocky Mountain juniper (*Pinus ponderosa/Juniperus scopulorum*) community.

4. Deciduous tree and shrub types.

Discussion of vegetation types

The Western wheatgrass/Junegrass/Sandberg bluegrass type was fairly common at some of the lower elevations in the vicinity of Colstrip. It was generally found on moderately heavy grazed sites with clay loam soils. The CIR photographs of the grassland types were similar in that most natural grassland areas appeared uniformly gray-green with little or no texture.

The Needle-and-thread/Western wheatgrass/Blue grama type was typically found throughout the study area on moderately grazed clay loams on gentle to steep south and west facing slopes. It was distinguished from the preceding type on the basis of slope aspect, exposure and relative grazing pressure. The CIR photographs of both of these grassland types were of similar color and texture.

The Cheatgrass type occurred primarily on areas that had been heavily grazed or otherwise disturbed. CIR photographs of this type had a pale orange cast where Cheatgrass was quite dense. Cheatgrass was widespread throughout both planning units but was only delineated when it occurred in above average abundance.

The Sweetclover type was typical of areas that had been recently disturbed such as abondoned or fallow fields. This type showed bright red on the CIR photographs.

The Silver sagebrush/grassland type typically occurred on soils of the more mesic sites such as along flood plains or in coulees with relatively high water availability. Common species associated with the dominant, Silver sage, were Broom snakeweed, Western wheatgrass, Junegrass, Needle-and-thread, Fringed sagewort and Common salsify. CIR photographs show this type appearing as pink in contrast to the surrounding grasslands or Big sagebrush areas.

The Big sagebrush/grassland type occurred on a variety of soils, slopes and exposures. This vegetation type appears on CIR photographs as dark gray-green areas of grainy texture. Species commonly associated with this type are Broom snakeweed, Western wheatgrass, Blue grama, and a variety of annual and perennial forbs.

The Skunkbrush/Bluebunch wheatgrass type was commonly found on the west to southeast exposures on relatively steep slopes at the higher elevations. The soils that supported this type ranged from sands to loams and were derived porcellanite material. Brown (1971) described this community and considered Yucca, Squaw currant, and *Eriogonum* to be commonly associated with the more dominant species, Bluebunch wheatgrass and Sideoats grama. Individual shrubs or clumps of *Rhus* were easily discerned on CIR photographs due to their intense red reflectance. This type had a "measled" appearance as a result of the excellent resolution of the individual groups of *Rhus*.

The Skunkbrush/Needle-and-thread type occurred more commonly on the more xeric slopes and was associated with such species as Broom snakeweed, Cheatgrass, and Sedges. This type and the previous type were very similar in CIR photographs and were separated on the basis of their proximity to porcellanite and their slope aspect and exposure.

The Snowberry/Prairie rose type occurred in the more mesic coulees that dissect the Ponderosa pine types at the higher elevations. Shrubs such as Silver sage, Chokecherry and Wild plum commonly grew in this type. This vegetation type appeared as bright red areas which contrasted with orange-brown reflectance of the surrounding Ponderosa pine. The dense shrub canopy produced a "fluffy" texture on the CIR photographs.

The Greasewood vegetation type was found predominantly on silt and clay soils with a high sodium content often found on the alluvial soils of stream terraces. Other species present in this type were Big sage and Shrubby seepweed. This type was virtually indistinguishable from the Big sagebrush/grassland type on the CIR photographs due to similarities in color and texture. A larger scale of photography would, perhaps, allow for the discrimination between these two types.

The Ponderosa pine/Bluebunch wheatgrass/Sideoats grama vegetation type occurred at the higher elevations of the study area, often on steep ridges. Skunkbrush was scattered throughout this type.

The Ponderosa pine/Western wheatgrass vegetation type occurred below the steeper ridges on the more rolling topography and was characterized by open or savannah-like stands of Ponderosa pine with Western or Bluebunch wheatgrasses commonly occurring as co-dominants. The herbaceous component was variable for this type but richer in species than the previous type and was separated on the basis of its savannah-like character. In many cases it was difficult to draw a distinct line between these two pine types.

The Ponderosa pine/Rocky Mountain juniper vegetation type usually occurred on relatively steep northeast facing slopes on coarse, rocky soils. Bluebunch wheatgrass was the dominant grass species and Skunkbush sumac, Big sage, Squaw currant and Broom snakeweed were common shrubs found in this type. It was difficult to visually separate this type from the other pine types on the CIR photographs since the canopies of both pine and juniper had similar reflectance characteristics. On some photographs the juniper foliage was recorded as more brown than the orange-brown foliage of the pine but this was not a reliable feature for separating the types. The relative density of the canopies and the slope aspect and exposure were utilized to more accurately discriminate between the *Pinus*/*Juniperus* type and the other *Pinus* types.

The Deciduous tree and shrub type occurred along the stream and river bottomlands and could also be described as a riparian community. The dominant tree species were: Quaking aspen, Boxelder, and Green ash. Some typical shrub species were: Silver sagebrush, Prairie rose, Snowberry, Chokecherry, and Buffaloberry. The herbaceous component of the vegetation for this type differed quite extensively from the herbaceous components of the other type due to differences in moisture availability and soils. The infrared reflectance of the broad-leaved deciduous species was recorded on the photographs as red or pink with individual trees or shrubs often being distinguishable. This type was often quite disturbed due to heavy grazing or agricultural development.

INTERPRETATIONS

Current Land Use

Current land use interpretation involved the delineation of irrigated and non-irrigated croplands and haylands, roads, trails, dwellings, abandoned buildings, corrals, oil and gas wells, powerlines, and pipelines.

The delineation of agricultural lands was accomplished with high accuracy. In general, hayland was differentiated from cropland by color tone, texture and pattern. Irrigated ditches can generally be detected and fields with pipe irrigation systems can be recognized by a color difference in the immediate area of irrigation, if the irrigation is currently or has recently been applied.

Ranch headquarters or used dwellings were differentiated from abandoned dwellings based on indicators of activity near the buildings.

Corrals with a recent history of use were also delineated, the primary features of recognition being bare soil reflectance or the light orange-brown reflectance associated with Cheatgrass. Corrals with no recent history of use were more difficult to detect.

Powerlines were delineated, The large metal towers associated with high capacity power transmission lines were relatively easy to resolve on 1:80,000 photography. A smaller transmission line (double wooden poles) that was constructed just prior to photography was easy to follow due to the fresh fill left from the holes and the tracks left from the associated construction equipment. However, older single or double wooden pole constructed transmission lines were difficult to follow and could only be delineated with extensive ground checks.

Several pipeline systems were also delineated in this study. Again, the age of the system and the soils and vegetative types traversed were the primary factors involved in detection of the line routes. For example, an older pipeline crossing an area of extensive dryland farming is difficult to detect on the photos and extensive field checking is required to precisely determine the pipeline route across such areas.

Present Erosion Condition

On public lands, the Bureau of Land Management evaluates the present erosion activity under existing management, topography, and climate as determined by seven soil surface factors. These factors include: soil movement, surface litter, surface rock, pedestalling, rills, flow patterns, and gullies. By evaluating these factors on the ground, the site can be assigned on Erosion Condition varying from stable to severe.

A similar erosion study from the CIR photography was accomplished. Initially, the contractor went into the field with a BLM Watershed Specialist and became familiar with the Bureau's erosion condition methods. This exercise had two important functions. The field familiarization enabled the contractor to become proficient in using the erosion condition form. In addition, a number of ground check points of known erosion condition were established throughout the study area for subsequent analysis on CIR photography.

It was determined that the seven soil surface factors could not generally be evaluated on the small scale CIR photography. However, successful results were obtained through interpretation by relying on photo-identifiable features such as the amount of ground cover, the condition of drainage bottoms, the presence of headwall cutting in drainages, and similar features. Comparison of photo-based estimates versus ground evaluations showed favorable results.

Erosion Susceptibility

An evaluation of the susceptibility of the soil to erosion if no vegetative cover was present was attempted through photo-interpretation. A comprehensive soil survey was lacking over most of the study area. The only photo-identifiable feature that could be related to erosion susceptibility was the degree of slope. A general relationship between erosion condition and susceptibility was inferred and modified by slope and other features.

Erosion susceptibility can be estimated from photography if intensive soil data exists. Without the soil data, susceptibility cannot be accurately determined from photos alone.

Surface Hydrology

The hydrology interpretation involved the delineation of wells, windmills, springs (unimproved and improved), reservoirs, diversion dams, streams, and ditches or canals.

Wells and windmills could be detected as spots of orange-brown (Cheatgrass) or bare soil reflectance due to the high degree of disturbance at these sites. Early in the study, it was recognized that salt block sites and/or cattle rub sites would probably have the same signature, therefore, the initial interpretation ignored such sites if they were near dams or reservoirs. However, later field checking showed that most of the sites near dams were in fact wells or windmills. In addition, most salt block sites and rub sites are in conjunction with a well or windmill and thus the interference was negligible. There was some difficulty, however, in distinguishing between wells and windmills. If the conditions were right, the windmill structure or its shadow could be identified.

Springs sites were detected by the vegetative characteristics associated with them. "Springy" areas are generally surrounded by lush vegetation or broad-leaf plants that reflect highly in the near infrared portion of the spectrum. The umimproved or potential spring sites either had surface water associated with them or had a water table near the surface. The improved spring sites usually consisted of a spring and dam or a spring and stock tank.

Reservoirs were classified according to water color into five general turbidity classes: white (highly turbid), pale blue, blue, dark blue and black (very low turbidity). No attempt was made to gather water quality data on the day of photography for quantification due to a lack of manpower at that date. However, this type of correlation (color tone - turbidity value) has been researched and will be attempted on future projects of this nature.

Diversion dams were delineated. In most cases they were a series of earth structures in fields or near the main drainages used for purposes of flood irrigating.

Porcellanite Outcrops

The delineation of porcellanite (i.e., clinker, red dog, scoria) outcrops was the easiest of all interpretive features. Wherever it outcropped, the surface would appear a chalky yellow color on the CIR photography. The boundaries of the outcrops were easily identified due to the fact they occurred in fairly discrete strata on ridges and knobs.

Rangeland Use

The delineation of rangeland utilization was based on the vegetative cover and species composition of areas that were accessible to grazing. The rangeland units were determined by the fencelines that could be discerned on the CIR photographs. The identification of fence lines depended on the degree of contrast on either side of the fence, due to differential grazing pressure. Heavily grazed areas were delineated due to the relatively greater amounts of Cheatgrass, Big sagebrush and exposed soil. Lightly grazed areas had fairly uniform vegetative ground cover with relatively little Cheatgrass, Big sagebrush and exposed soil. Moderately grazed areas fell somewhere between the lightly and heavily grazed sites.

Several problems were encountered with the delineation of rangeland utilization. One problem concerned the errors in fenceline identification. It was often not possible to delineate existing fencelines because the vegetative ground cover and species composition were similar on both sides of the fence. Another problem concerned the interpretation of rangeland utilization. Some areas such as the "breaks" or "badlands" had sparse ground cover with relatively extensive stands of Big sagebrush. It is not always possible to attribute the presence of exposed soil and Big sagebrush to grazing pressure alone. Some areas, due to edaphic factors, are not compatible with the vigorous growth of desirable range species. High clay content, salinity and susceptibility to erosion contribute to spare vegetative ground cover. On CIR photographs it is difficult to determine whether vegetative characteristics are a result of grazing or edaphic factors, particularly where fenceline contrasts are not readily apparent. Differences in rangeland utilization are apparent on CIR photography, however, further efforts toward quantification of these differences are necessary.

Potential Wildlife Habitat

Potential habitat for each major and economically important wildlife species found in the inventory unit was delineated. These species or types consisted of the following:

1. Pronghorn antelope
2. Mule deer
3. White-tailed deer
4. Sage grouse
5. Sharp-tailed grouse
6. Ring-necked pheasant
7. Hungarian partridge
8. Upland marsh areas
9. Natural water bodies
10. Prairie dog towns
11. Beaver
12. Ant infested areas
13. Merriam's turkey
14. Fisheries
15. Geese

Each major vegetation type demarcated was considered to have a certain value for wildlife based upon the specific habitat requirements of each of the above mentioned animals or areas. In an attempt to quantify this value, a numerical rating of 1 for primary habitat, 2 for secondary habitat, and 3 for tertiary habitat was assigned to each major vegetation type or geographical area. Although these value ratings were rather subjective, they did provide a basis for comparison between vegetative types and their importance to a particular wildlife species.

It should be stressed that photo interpretation such as this can be used to identify potential or possible wildlife habitat types. The interpretation is based primarily on two things; the vegetative communities identified from the photography and habitat requirements for these species in this area. These habitat requirements are determined through a search of pertinent written research.

Data such as this are very useful as long as the users (i. e.,) BLM Wildlife Biologists) realize the rationale behind it and what criteria were used during the interpretation.

CONCLUSION

This inventory, based on interpretation of small scale color infrared aerial photography, provided the BLM with high quality surface resource data for 3,000 square miles of lands associated with strippable coal deposits in southeastern Montana. The techniques proved accurate, practical and cost effective. The data will serve as an excellent baseline from which to assess the potential impacts of possible future coal strip mining and its related activities.

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MONITORING WILDLIFE PARAMETERS PRIOR TO EXTENSIVE STRIP MINING AND OPERATION OF COAL-FIRED STEAM GENERATING PLANTS AT COLSTRIP, MONTANA

William F. Schwarzkoph and Raymond R. Austin*

INTRODUCTION

Ecological Consulting Service has been actively engaged in wildlife and vegetation studies in the Fort Union coal fields since late summer, 1972. Out studies have been funded by power and coal companies working in the Fort Union coal fields. These studies are designed to obtain a four-season baseline, and annual monitoring of specific wildlife parameters for comparison year by year. The data obtained have valuable applications--both in defining some of the existing environmental factors and providing information which can assist reclamation programs. These studies also provide information concerning wildlife and vegetation on specific areas for which little or no data were previously available. Currently, we have on-going wildlife studies with companies such as Montana Power, Peabody Coal, and Westmoreland Resources.

For purposes of the written report of these Symposium Proceedings, we are listing below the captions of slides used in the verbal presentation of the paper, and parallel to them a running text and commentary.

SLIDES AND COMMENTARY

SLIDE NO. 1: Location of study area in southeastern Montana. SLIDE NO. 2: Close-up of study area showing creeks and roads.	The data to be presented here today concerns our 200-square mile study area surrounding Colstrip, Montana We refer to it as the 10x20, as it is 10 miles wide and 20 miles long, with the long axis lying in a northwest-southwest direction. This study has been funded by the Montana Power Company.
SLIDE NO. 3: Eastern ponderosa pine vegetation formation.	The vegetation of the Colstrip vicinity has been described by Küchler (4) as an eastern ponderosa pine vegetation formation, and as a *Pinus ponderosa/Agropyron spicatum* habitat type within the *Pinus ponderosa* series by Pfister and others (5).
	We quantitatively sampled the low-growing plant taxa at 75 different sites with a method similar to that used by Daubenmire (2). Constancy, canopy coverage and frequency of forage classes and plant taxa in 20 2x5 decimeter frames along a 100-foot line were determined for these sites. A plant collection was also made. Habitat types described by Ecological Consulting

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Service on the 10x20 study area consisted of the following:

SLIDE NO. 4: Grassland habitat type.

Grassland habitat type occurred as open non-shrub and non-timber areas. This type consisted of several grass communities or associations, including such species as needle-and-thread, threadleaf sedge, western wheatgrass, cheatgrass, Japanese chess, little bluestem, junegrass, and others. Grass associations were not considered separately as habitat types when being related to wildlife use.

SLIDE NO. 5: Big Sagebrush-grassland habitat type.

Big sagebrush-grassland habitat type occurred on benches, medium to steep footslopes, and rough badlands. Common shrubs were big sagebrush and broom snakeweed. Grasses usually consisted of Junegrass, western wheatgrass, and blue grama.

SLIDE NO. 6: Silver sagebrush-grassland habitat type.

Silver sagebrush-grassland habitat type occurred on lower footslopes and in mesic swales and coulees. Common shrubs were silver sagebrush and broom snakeweed. The common grasses consisted of western wheatgrass, Japanese chess, and cheatgrass.

SLIDE NO. 7: Skunkbush-grassland habitat type.

Skunkbush-grassland habitat type occurred in open areas as well as near timbered pine areas. Skunkbush sumac, broom snakeweed, and prairie rose were common shrubs. Grasses consisted of bluebunch wheatgrass, junegrass, needle-and-thread, and Japanese chess.

SLIDE NO. 8: Saltbush-rabbitbrush habitat type.

Saltbush-rabbitbrush habitat type was found on extremely severe sites with steep slopes. Soils were of very fine clays. They have been referred to as gumbo knobs. Shrubs occurring at these sites were shadscale saltbush and rubber rabbitbrush. Grasses consisted of Indian ricegrass and bluebunch wheatgrass.

SLIDE NO. 9: Ponderosa pine-grassland habitat type.

Ponderosa pine-grassland habitat type was a major type in the area and occurred on ridges and at higher elevations on the study area. The understory varied from almost barren ground under dense canopies to shrubby areas under an open canopy. Ponderosa pine was the dominant tree, with some scattered Rocky Mountain juniper occurring also. Shrubs included skunkbush sumac and snowberry. Grasses consisted of bluebunch wheatgrass, sideoats grama, and little bluestem.

SLIDE NO. 10: Ponderosa pine-juniper habitat type.

Ponderosa pine-juniper habitat type occurred on steep north-facing slopes. The dominant tree species was Rocky Mountain juniper, with some ponderosa pine. Grasses included bluebunch, western wheatgrass, and junegrass.

SLIDE NO. 11: Creek bottom habitat type.

Creek bottom habitat type occurred on moist drainage bottomlands such as Rosebud and Armell's Creeks. Trees consisted of plains cottonwood, box elder, and green ash. Shrubs consisted of snowberry, silver sagebrush, and prairie rose. Grasses included Kentucky bluegrass, western wheatgrass, and foxtail barley.

SLIDE NO. 12: Agricultural habitat type.

Agricultural habitat types consisted of alfalfa or native hay meadows, winter wheat and it's associated fallow.

SLIDE NO 13: Disturbed grassland habitat type.

Disturbed grassland occurred where cropland was seeded back into rangeland. Common plant species occurring here were crested wheatgrass and yellow sweetclover.

SLIDE NO. 14: Roadside habitat type.

Other disturbed areas included roadsides and reclamation.

SLIDE NO. 15: Reclamation habitat type.

Observations of wildlife were recorded while in the field and during periodic flights over the study area. This year we are flying the 10x20 twice a month.

SLIDE NO. 16: Mule deer - Most common game animal in the Colstrip vicinity.

SLIDE NO. 17: Mule deer distribution.

Mule deer were the most abundant big game species on the 10x20. Their distribution was throughout the area, but more mule deer were generally observed along the divide between the east and west forks of Armell's Creeks, greenleaf ridge, the divides between Spring and Pony Creeks and Pony and Cow Creeks, and the timbered ridges just north of the Rosebud Creek road.

SLIDE NO. 18: Excellent mule deer habitat in the Colstrip vicinity.

SLIDE NO. 19: Use of habitat types by mule deer.

Mule deer appeared to use areas most where a diversity of the two timber types and the three shrub-grassland types existed in close association. During summer and autumn, the creek bottom habitat types were used extensively, especially at night.

SLIDE NO. 20: Sex and age classes of mule deer.

Autumn fawn: doe ratios for 1973 and 1974 were 59 and 68:100, respectively. Fawn:adult ratios for January 1974 and 1975 were 41 and 49:100, respectively.

SLIDE NO. 21: Autumn food habits of mule deer.

Autumn food habits of mule deer, based on 19 rumen samples taken from hunter-killed deer in the Colstrip vicinity, indicated a high use of browse--85%. Skunkbush sumac berries and leaves contributed 60% of the autumn diet. There was a decrease in the use of skunkbush from October to November and a subsequent increase in the use of silver sagebrush and snowberry.

SLIDE NO. 22: Antelope in the Colstrip vicinity.

SLIDE NO. 23: Antelope distribution.

Antelope were also numerous on the 10x 20, but displayed a definite shift to specific areas in winter. Wintering areas, consisting of large expanses of big sagebrush, were located at lower Pony and Cow Creeks and near the heads of Corral, McGilvery, and Seven-Mile Creeks. Small herds were observed wintering along Miller Creek and near upper Stocker and the east fork of Armell's Creeks. A large wintering area exists just north of the 10x20 along Spring Creek.

SLIDE NO. 24: Excellent antelope habitat in the Colstrip vicinity.

Habitat types used most by antelope were grassland, big sagebrush-grassland, and silver sagebrush-grassland.

SLIDE NO. 25: Use of habitat types by antelope.

SLIDE NO. 26: Sex and age classes of antelope.

Fawn:doe ratios for antelope recorded during September 1973 and August 1974 were 35 and 40:100, respectively. This is quite low for antelope and the reason for this low productivity is not really known. One factor may be that the 10x20 area is not really optimum antelope habitat due to the timbered nature of the area.

SLIDE NO. 27: Autumn food habits of antelope.

Browse was the most important forage class during the autumn food habits study, based on eight rumen samples collected from hunter-killed animals. Silver sagebrush and snowberry accounted for 40 and 28% of the diet, respectively.

SLIDE NO. 28: Big game browse utilization.

Big game browse utilization transects were conducted during the springs of 1973 and 1974 by a method similar to that discussed by Cole (1). Only 3 of 15 transects indicated leader use of greater than 25%. These three sites consisted of rubber rabbitbrush and had leader use recorded up to 75%. The remaining transects, with such species as big sagebrush, silver sagebrush, and skunkbush sumac, had very light utilization of less than

25%. This may be attributable to the comparitively mild and snow-free winters these two years.

SLIDE NO. 29: Sharp-tailed grouse - Most common game bird in the Colstrip vicinity.

Sharp-tailed grouse were the most numerous game bird on the 10x20. Areas offering good to excellent sharptail habitat were upper Corral Creek, mid Stocker Creek, the Pony-Cow Creek divide and the extreme southeastern corner of the 10x20.

SLIDE NO. 30: Excellent sharptail habitat in the Colstrip vicinity.

Good sharptail habitat occurred in areas with a diversity of open grasslands near shrubby coulees and stands of ponderosa pine and skunkbush.

SLIDE NO. 31: Location of sharptail dancing grounds.

During the spring of 1973, 13 sharptail dancing grounds were discovered on the 10x 20. In the spring of 1974, 7 additional dancing grounds were found for a total of 20, and we feel at least 3 or 4 more exist on the area.

SLIDE NO. 32: Location of sharptail dancing grounds on a knoll.

Sixteen of the 20 dancing grounds were located at definite knolls, knobs, or ridges.

SLIDE NO. 33: View at center of a sharptail dancing ground.

SLIDE NO. 34: View just off a sharptail dancing ground.

Vegetation transects were conducted, as previously described, on each dancing ground to determine ground characteristics, canopy coverage, and frequency of plant taxa. Common grasses occurring on dancing grounds consisted of needle-and-thread, junegrass, Japanese chess, western wheatgrass, and threadleaf sedge. Vegetation at the center of the dancing grounds was beaten down considerably by the dancing activity of the sharptails. Elevations of dancing grounds ranged from 2,910 feet to 3,600 feet.

SLIDE NO. 35: Male prairie grouse densities during the springs of 1973 and 1974.

In an attempt to determine fluctuations in male sharptail breeding densities from year to year, numbers of male sharptails were counted and recorded on each dancing ground in the springs of 1973 and 1974. There was an average of 12.7 and 13.2 males on each of the 13 dancing grounds in 1973 and 1974, respectively, and an average of 11.8 males/dancing ground for all 20 grounds observed in 1974.

SLIDE NO. 36: Autumn food habits of sharp-tailed grouse (September 1973).

SLIDE NO. 37: Autumn

Eleven crops were collected from hunter-killed sharptails during October and November 1973. Skunkbush berries, rose hips, and snowberries accounted for 80.5% of the diet. During September 1974, 12 crops were collected from hunter-killed birds, food habits of sharp-tailed grouse (October-November 1974).

and grasshoppers accounted for 77.6% of the diet while skunkbush berries, rose hips, and snowberries accounted for 16.1%.

SLIDE NO. 38: Pheasants in the Colstrip vicinity.

SLIDE NO. 39: Pheasant distribution in the Colstrip vicinity.

Pheasant distribution was basically limited to the agricultural, creek bottom, and nearby roadside habitat types along Rosebud and the east fork of Armell's Creek.

SLIDE NO. 40: Rosebud Creek pheasant crowing count route.

SLIDE NO.41: Armell's Creek pheasant crowing count route.

Spring cock crowing counts similar to that described by Kimball(3) were conducted along Rosebud and the east fork of Armell's Creeks in 1973 and 1974. Armell's Creek, felt to be only marginal pheasant habitat, had very low counts of 2.6 and 2.7 calls/stop for 1973 and 1974, respectively. Counts along the Rosebud Creek route rose from 17.1 to 26.3 calls/stop for 1973 and 1974, respectively. Although the accuracy of crowing counts and the success with which they can be used depends on several factors, it was felt that the pheasant population along Rosebud Creek did, in fact, increase. Rosebud Creek offers a diverse cover-food source association among the related creek bottom, agricultural, and roadside habitat types.

SLIDE NO. 42: Sage grouse in the Colstrip vicinity.

Other less common game species observed on the 10x20 were white-tailed deer, sage grouse, and Hungarian partridge.

SLIDE NO. 43: Location of sage grouse strutting ground.

One sage grouse strutting ground was found on the 10x20. Fifteen males were counted in 1974 and will be monitored again in 1975. Dominant grasses at this site were Japanese chess, western wheatgrass, cheatgrass, and needle-and-thread. It was located in an open grassland habitat type but near a large stand of big sagebrush.

SLIDE NO. 44: Prairie dog town on the 10x20 study area.

SLIDE NO. 45: Location of prairie dog town.

Large predators consisted of coyotes, red foxes, and bobcats. Endangered species that could occur in the area are the perregrine falcon and the black-footed ferret. Neither were observed nor was any sign of these species noted. One prairie dog town doesexist on the 10x20, but no sign of ferrets have been noted to date and particular emphasis has been placed on observing this dog town for ferret sign.

SLIDE NO. 46: Western deer mouse - Most common small mammal in the Colstrip vicinity.

Some trapping with snap traps indicated that western deer mice and prairie voles appear to be the most common small mammals.

SLIDE NO. 47: Rosebud Creek.

Fishes seined and identified at two locations along Rosebud Creek consisted of mountain suckers, shorthead red-horses, longnose dace, and flathead chubs.

This year we are continuing to monitor these same wildlife parameters and have planned some additional items which include population estimates of small mammals in some locations, more big game food habits for other seasons, benthic studies, and more work on raptors and songbirds.

We have been developing a program for evaluating the composition and diversity of the habitat being utilized by the major wildlife species in the areas we are working in. We refer to it as the habitat diversity and utilization program, and we should have some of our past data computer analyzed with it in a month or two.

SLIDE NO. 48: Infrared aerial photo with overlay.

The initial step in this program is to make a detailed habitat map of the study area which delineates each unit of each habitat type. We have been using false-color infrared aerial photography at each study area in combination with extensive ground checks to make these habitat maps. The various habitat types can be determined from the photos and outlined on a transparent overlay.

SLIDE NO. 49: Sample area map with grid overlay.

A grid overlay is then placed over the habitat map which delineates square blocks, or coordinates. The habitat units which occur within each coordinate are then tabulated, along with the relative proportion of each. By updating the habitat map data each year for any changes in the area, we can analyze any number of years of wildlife observations at one time with this program, and the appropriate habitat data will be used for whatever year the observation was made.

SLIDES NO. 50, 51, 52, 53: Sample area maps, years 1, 2, 3, and 4.

These next slides show sample area maps which we used for sample data to test the program. They depict changes in an area over a 4-year period, which would be similar to the types of changes occurring in the Colstrip area.

SLIDE NO. 54. Sample area map, years 1-4.

This last map represents the habitat map which has been updated for the 4-year period, and which can be used to depict the conditions during any of the four years, if used in conjunction with the habitat unit data.

SLIDE NO. 55: Observation table.

When each observation of a major wildlife species is made on the study area, the location is noted, and this location can be correlated with the coordinate system of the habitat map. A certain area, or number of coordinates, around the observation site is then analyzed. The size of this area will vary depending on the species and season of the observation. Within this area, then, the number of habitat units and the relative proportion of each is determined, and an index of diversity of that area is calculated, based on these data.

SLIDE NO. 56: Habitat utilization table.

Tables can then be generated which summarize, or average, the analyses of each observation. One such table gives the frequency of occurrence of each habitat type in the area around observation sites, as well as the average percent of this area which each habitat type occupied. Such a table will be generated for each species for each year or group of years being considered. These tables are also broken down by season.

SLIDE NO. 57: Habitat diversity table.

Another table which is generated is one giving the average index of diversity of the area around the observation sites. This table is broken down by species and season for each year or time period.

A series of random points can then be selected on the study area and analyzed in the same manner as the actual observation data and using the same habitat data. This forms a basis for making statistical comparisons and tests. Tests can then be made of the utilization of the various habitat types and of the diversity of this habitat being utilized for any year or time span. Then after several years of monitoring, tests can be made to check for any changes in patterns of habitat use by these species. This will be particularly important in the Colstrip area for determining the effects of the mining on wildlife, and for determining possible reclamation practices which will be beneficial to wildlife. It will also help determine the response of wildlife to the various reclaimed areas.

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ANALYSIS OF ECOLOGICAL SUITABILITY FOR MULTIPLE-USE PLANNING ON THE LITTLE MISSOURI NATIONAL GRASSLAND, WESTERN NORTH DAKOTA

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INTRODUCTION

The Dakotas Planning Team of the U.S. Forest Service, Custer National Forest has developed a practical multiple-use planning process for application in the management of terrestrial ecosystems. The Team has used this process for the two multiple-use plans and accompanying environmental statements to provide land management direction for the Little Missouri National Grassland of western North Dakota. The Team completed these plans for over one million federal acres in less than two years. The area is within the Fort Union Coal Field, and coal mining potential was one of the primary motivations for this multiple-use planning effort.

THE SYSTEM OF ANALYSIS

The heart of this planning process is a system for the analysis of ecological suitability (or sensitivity) which allows for varying conditions. Suitability, as used here, indicates the degree of potential environmental impacts that could result from application of an activity for given characteristics of any ecosystem. Thus, an activity is suitable in a given ecosystem if only relatively minor or no constraints are necessary to prevent significant environmental impacts or land damage. Suitability does not refer to the feasibility of, or to the potential for, commodity production in an activity, although feasibility or potential production are frequently a result of this environmental suitability.

This system for analysis of ecological suitability utilizes ecosystems as identified in each planning unit. The term "ecosystem," as used here, is a land unit with a certain set of characteristics. (Each set of characteristics will result in the need for specific management.) These important characteristics (as they apply to the planning unit) must be identified before suitability can be determined. The characteristics are each divided into specific levels, then used to describe each ecosystem; this is the primary emphasis of the resource inventory. These sets of ecosystem characteristics are reviewed in an interdisciplinary team session. The Ecosystem Characteristics Table for the Rolling Prairie Planning is shown in Figure 1. A document entitled "Background Reports" provides further description and definition of the ecosystem characteristic levels, with quantifications where possible.

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A set of potential activities for analysis is condensed from a listing of area needs and demands. Definitions are carefully formulated for each activity, and the activity (or activities) fulfilling each need or demand is listed.

The analysis of ecological suitability of (or sensitivity to) these potential management activities is done by the interdisciplinary team (including Ranger District management representatives) in a series of sessions, utilizing the team's best judgement. Rules are essential for these team sessions for environmental analysis. The following rules are used by the Dakotas Planning Team:

1. Evaluations are made based upon existing laws, regulations, and policies with good enforcement, adherence to Part I of the Custer National Forest Multiple Use Plan, and the use of normal "good land management" practices.

2. Evaluations concern a theoretical parcel of land with given characteristics and activities.

3. Evaluations are based on the activities "as we know them now" (potential new laws or unproven technology cannot be evaluated).

4. Activity evaluations are considered for approximately a ten-year period from the start of an activity, though individual activities may have a different time duration. (Ecological evaluations have no time constraint considerations.)

5. Evaluations are made of the potential impacts or conflicts at the site of the activity or the immediate vicinity.

6. Evaluations are judged to be true 75 percent of the time for each activity. Exceptions to this rule must be evaluated by the resource manager on a case-by-case basis in separate project environmental analyses. This rule is very important because it keeps the planning from getting bogged down by exceptions.

Ecological suitability is displayed with symbols. The Team uses symbols rather than numbers to avoid the tendency that people have to add numbers and arrive at erroneous conclusions because of numerical sums. These symbols indicate the relative severity of restrictions or constraints necessary to conduct the activity while protecting the environment. Four levels of symbols are used because more levels can seldom be clearly identified and because a middle symbol would not provide a decisive analysis. These symbols are as follows:

○ Suitable (Minor or negligible potential ecological damage)

⊕ Moderately suitable (Some potential ecological damage)

⊛ Low suitable (Substantial potential ecological damage)

● Not suitable (Extensive potential ecological damage)

N/A Not Applicable

The Team proceeds by evaluating the ecological suitability of (or potential ecological damage from) each given activity for each ecosystem characteristic, with the hypothetical situation (in each case) that that characteristic is the only limiting factor, momentarily disregarding all other characterics. These decisions result in an important and complex matrix entitled Suitability of Activities by Characteristic (example in Figure 2). For creating this matrix, individual ecosystems are normally ignored, though they may be used as examples during discussion. Interaction between characteristics is not considered until later, in the alternative formulation phase.

The example in Figure 2 contains 1,311 decisions about the potential impacts or suitability of 19 activities with each of 69 levels within 19 ecosystem characteristics. Refer to the upper left corner of Figure 2 for a specific example of evaluation for ecological suitability--for canals, resulting from flood hazard: The conclusions of the Team were that canals could potentially cause substantial ecological damage on land with high flood hazard, some ecological damage on land with medium flood hazard, and negligible ecological damage on land with low or very low flood hazard. Constraints or restrictions on individual projects may be able to prevent or to mitigate any ecological damage resulting from the suitability of a certain characteristic to the activity, and the need for restrictions is readily traced to that limiting characteristic.

The next step after completion of the Suitability of Activities by Characteristic matrix is the mechanical process of transposing the suitability information to a separate chart for each activity. This job does not require interdisciplinary team action and can be accomplished by a trained clerk or programmed computer. These Activity/Ecosystem Suitability Charts (example in Figures 3a and 3b) are a result of the combination of the information shown in Figures 1 and 2 and show the suitability of each activity for each characteristic of each ecosystem. (Abbreviations in these charts are from the Ecosystem Characteristics table in Figure 1.) This step can be compared to a computers operation: Ecosystem Characteristics (Figure 1) are the data, Suitability of Activities by Characteristic (Figure 2) is the computer program, and the Activity/Ecosystem Suitability Charts (Figures 3a and 3b) are the printouts.

The set of Activity/Ecosystem Suitability Charts (one for each activity) is the major product of the analysis phase. These Charts are important tools for alternative formulation, decision-making, and project application (environmental analysis). Each activity chart can also be summarized for each ecosystem by grouping the characteristics into categories and displaying the rating (or symbol) on the basis of the most limiting characteristic in each category (or overall, for all characteristics).

These characteristics are categorized in the examples in Figures 2 and 3 as "Physical" or "P" for critical physical characteristics affecting the basic soil and water resource of each ecosystem and as "Biotic" or "B" for mostly biotic characteristics. On the last three lines of Figures 3a and 3b are combinations of these "physical" characteristics, "biotic" characteristics, and overall (all) characteristics, respectively, on the basis of the most limiting (least suitable) characteristic in each ecosystem. These last three lines from each Activity/ Ecosystem Suitability Chart are then copied onto three summary tables -- Physical Suitability (example in Figure 4), Biotic Suitability, and Overall Suitability. These charts can then be used to systematically formulate and analyze alternatives: Physical Suitability gives primary limitations of activities for basic suitability in alternative formulation; Biotic Suitability provides a good checklist of many environmental trade-offs; and Overall Suitability provides a more complete checklist of environmental factors, though it is often overly restrictive because relative importance of these many factors is not considered. In alternative formulation, an activity is generally permissible on a site if the physical suitability is suitable or moderately suitable (○ or ⊕) but not if it is low suitable or not suitable (⊛ or ●). (The ecosystem characteristics for future planning units have been divided into three categories of importance labeled primary, secondary, and other; these designations are more accurate and more useful for alternative formulation.)

An example of the use of this system can be seen in Figure 3a. For the River Bottoms, Ecosystem 1, the most limiting factor (characteristic) for the construction of roads, pipelines, powerlines, and seismic activity is its high flood hazard (also shown by the Ecosystem Characteristics table in Figure 1). A low suitability (⊛) for this activity is shown by the Suitability of Activities by Characteristic Matrix (Figure 2) when the flood hazard is high (independent of ecosystem). Therefore, this activity should not ordinarily be allowed in Ecosystem 1. If it is allowed, severe constraints are necessary in order to protect the environment.

The planning process using this system forms the basis for the Multiple-Use Plans for the Little Missouri National Grasslands: The Badlands Unit (1, 2) and the Rolling Prairie Unit (3). However, these plans are not just sitting on a shelf -- the Ranger Districts are currently using the plans as direction, and the system for analysis of ecological suitability as a management tool in project environmental analyses.

These districts have developed a form utilizing this system for Environmental Analysis Reports (EAR form); this EAR form is shown on Figure 5 (front) and Figure 6 (backside). The front of the EAR form (Figure 5) is used to document project data, mitigating restrictions, and their decision-making rationale for each proposed project. Use of the backside of the EAR form (Figure 6) requires checking the information in the Activity/Ecosystem Suitability Charts (example in Figure 3). This project EAR procedure fulfills a major planning goal -- critical factors can be readily traced, while giving the land managers both the latitude and the direction needed to make responsible management decisions.

CONCLUSION

In conclusion, this method of analysis of ecological suitability provides a systematic, interdisciplinary approach to resource inventories and assessment of environmental impacts from uses, for planning. In this way, this analysis system helps to provide for continued demonstration of sound land stewardship

Ecosystem Characteristics
Rolling Prairie Planning Unit
Little Missouri National Grasslands

Figure 1

	ECOSYSTEM	(1) RIVER BOTTOM	(2) HARDWOOD DRAW	(4a) UPLAND GRASSLAND (CLAYEY)	(4b) UPLAND GRASSLAND (SANDY)	(5a) ROLLING GRASSLAND (CLAYEY)	(5b) ROLLING GRASSLAND (SANDY)	(6) TERRACES	(7) UPLAND BREAKS	(8) ROCKLAND	(9) RIVER BREAKS	(10) TOE SLOPES-	(11) HILLY SCORIA
	SOIL PARENT MATERIAL	ALLUVIUM	ALLUVIUM AND SHALES	SHALES AND GLACIAL TILL	SANDSTONE	SHALES AND GLACIAL TILL	SANDSTONE	ALLUVIUM	SHALES AND SANDSTONE	SANDSTONE	SHALES AND SANDSTONE	ALLUVIUM AND SHALES	PORCELLANITE (SCORIA)
PHYSICAL	FLOOD HAZARD	HIGH	MEDIUM	LOW	LOW	VERY LOW	VERY LOW	LOW	VERY LOW	VERY LOW	VERY LOW	LOW	VERY LOW
PHYSICAL	MASS FAILURE HAZARD	LOW	MEDIUM	HIGH	LOW	LOW	LOW	LOW	HIGH	MEDIUM	HIGH	LOW	LOW
PHYSICAL	SLOPE (PERCENTAGE)	0-3	3-15	15-40	15-40	3-15	3-15	0-3	40-70	15-40	70+	3-15	15-40
PHYSICAL	WATER EROSION HAZARD	VERY HIGH	VERY HIGH	HIGH	MODERATE	HIGH	MODERATE	MODERATE	VERY HIGH	HIGH	VERY HIGH	HIGH	LOW
PHYSICAL	WIND EROSION HAZARD	LOW	MEDIUM	MEDIUM	HIGH	MEDIUM	HIGH	LOW	LOW	MEDIUM	LOW	LOW	LOW
BIOTIC	NON-GAME HABITAT	VERY HIGH	VERY HIGH	LOW	LOW	LOW	LOW	MODERATE	MODERATE	MODERATE	HIGH	LOW	MODERATE
BIOTIC	THREATENED OR UNIQUE ANIMAL HABITAT	MODERATE	LOW	MODERATE	MODERATE	VERY HIGH	VERY HIGH	VERY HIGH	MODERATE	MODERATE	VERY HIGH	HIGH	HIGH
BIOTIC	SMALL GAME HABITAT	HIGH	VERY HIGH	VERY HIGH	VERY HIGH	HIGH	HIGH	LOW	LOW	HIGH	MODERATE	LOW	LOW
BIOTIC	BIG GAME HABITAT	HIGH	VERY HIGH	MODERATE	MODERATE	HIGH	HIGH	MODERATE	MODERATE	MODERATE	VERY HIGH	LOW	MODERATE
BIOTIC	FERTILIZER RESPONSE	MODERATE	MODERATE	LOW	LOW	MODERATE	LOW	MODERATE	VERY LOW	LOW	VERY LOW	HIGH	LOW
BIOTIC	ROOTING ZONE DEPTH	DEEP	DEEP	SHALLOW	SHALLOW	DEEP	DEEP	DEEP	VERY SHALLOW	SHALLOW	VERY SHALLOW	DEEP	MODERATE
BIOTIC	DOMINANT VEGETATION	TREES, SHRUBS, GRASS	SHRUBS, TREES	GRASS, SHRUBS	GRASS, SHRUBS	GRASS	GRASS	GRASS, SHRUBS	SHRUBS	GRASS, SHRUBS	SHRUBS	GRASS	GRASS, SHRUBS
BIOTIC	FORAGE PRODUCTIVITY	HIGH	HIGH	LOW	LOW	MEDIUM	LOW	HIGH	VERY LOW	LOW	VERY LOW	HIGH	LOW
B	VISUAL ATTRACTIVENESS	HIGH	MEDIUM	HIGH	HIGH	LOW	LOW	MEDIUM	VERY HIGH	VERY HIGH	VERY HIGH	LOW	HIGH
	DEPTH TO WATER TABLE	SHALLOW	MEDIUM	USUALLY DEEP	USUALLY DEEP	USUALLY DEEP	USUALLY DEEP	MEDIUM	USUALLY DEEP	MEDIUM	USUALLY DEEP	MEDIUM	USUALLY DEEP
	PERMEABILITY	MODERATE - RAPID	SLOW	SLOW	RAPID	SLOW	RAPID	MODERATE	SLOW	RAPID	SLOW	SLOW	RAPID
	SURFACE WATER RUNOFF	HIGH	HIGH	HIGH	LOW	HIGH	LOW	MEDIUM	HIGH	LOW	HIGH	HIGH	LOW
	WATER STORAGE CAPACITY	MEDIUM	HIGH	LOW	LOW	MEDIUM	LOW	HIGH	LOW	LOW	LOW	HIGH	LOW
	PROTECTION FROM WEATHER EXPOSURE	MEDIUM	MEDIUM	LOW	LOW	LOW	LOW	LOW	HIGH	LOW	HIGH	LOW	LOW
	COMMON VARIETY MINERALS	GRAVEL MINOR		SCORIA		SCORIA, GRAVEL		GRAVEL MINOR					SCORIA
		1	2	4a	4b	5a	6a	6	7	8	9	10	11

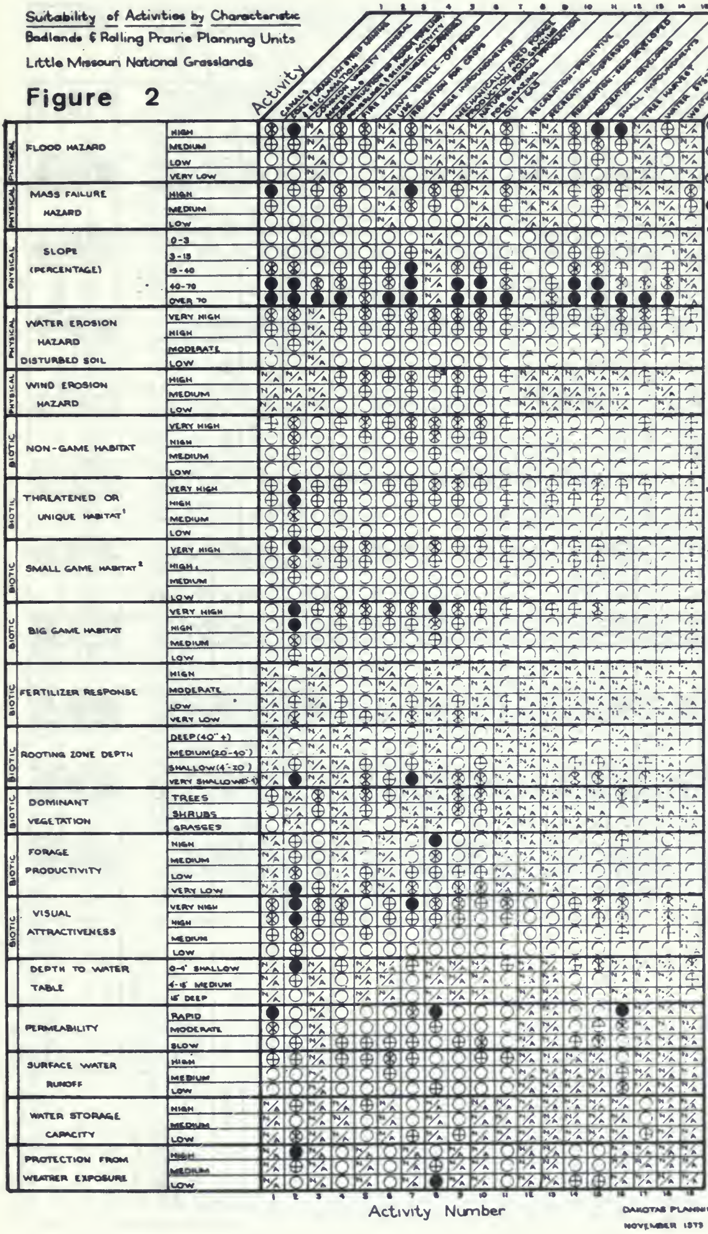
ECOSYSTEM NUMBER

GENERAL NOTE
MANY CHARACTERISTICS VARY SIGNIFICANTLY WITHIN ECOSYSTEMS

DAKOTAS PLANNING TEAM
APRIL 1974

Suitability of Activities by Characteristic
Badlands & Rolling Prairie Planning Units
Little Missouri National Grasslands

Figure 2


Activity
1 Canals
2 Coal/Uranium strip mining & reclamation
3 Common variety mineral materials
4 Construction of roads, pipelines
5 Geophysical & seismic activity
6 Fire management (burning)
7 Heavy vehicle - off road use
8 Irrigation for crops
9 Large impoundments
10 Mechanically aided forage production for grazing
11 Natural forage production for grazing
12 Oil & gas
13 Recreation - primitive
14 Recreation - dispersed
15 Recreation - semi-developed
16 Recreation - developed
17 Small impoundments
18 Tree harvest
19 Water systems
Weather modification
PHYSICAL
FLOOD HAZARD
HIGH
MEDIUM
LOW
VERY LOW
PHYSICAL
MASS FAILURE HAZARD
HIGH
MEDIUM
LOW
PHYSICAL
SLOPE (PERCENTAGE)
0-3
3-15
15-40
40-70
OVER 70
PHYSICAL
WATER EROSION HAZARD DISTURBED SOIL
VERY HIGH
HIGH
MODERATE
LOW
PHYSICAL
WIND EROSION HAZARD
HIGH
MEDIUM
LOW
BIOTIC
NON-GAME HABITAT
VERY HIGH
HIGH
MEDIUM
LOW
BIOTIC
THREATENED OR UNIQUE HABITAT 1
VERY HIGH
HIGH
MEDIUM
LOW
BIOTIC
SMALL GAME HABITAT 2
VERY HIGH
HIGH
MEDIUM
LOW
BIOTIC
BIG GAME HABITAT
VERY HIGH
HIGH
MEDIUM
LOW
BIOTIC
FERTILIZER RESPONSE
HIGH
MODERATE
LOW
VERY LOW
BIOTIC
ROOTING ZONE DEPTH
DEEP (40" +)
MEDIUM (20-40")
SHALLOW (4-20")
VERY SHALLOW (0-4")
BIOTIC
DOMINANT VEGETATION
TREES
SHRUBS
GRASSES
BIOTIC
FORAGE PRODUCTIVITY
HIGH
MEDIUM
LOW
VERY LOW
BIOTIC
VISUAL ATTRACTIVENESS
VERY HIGH
HIGH
MEDIUM
LOW
DEPTH TO WATER TABLE
0-4' SHALLOW
4-15' MEDIUM
15' DEEP
PERMEABILITY
RAPID
MODERATE
SLOW
SURFACE WATER RUNOFF
HIGH
MEDIUM
LOW
WATER STORAGE CAPACITY
HIGH
MEDIUM
LOW
PROTECTION FROM WEATHER EXPOSURE
HIGH
MEDIUM
LOW
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
Activity Number

Key
○ - SUITABLE (MINOR OR NEGLIGIBLE POTENTIAL ECOLOGICAL DAMAGE)
⊕ - MODERATELY SUITABLE (SOME POTENTIAL ECOLOGICAL DAMAGE)
⊗ - LOW SUITABILITY (SUBSTANTIAL POTENTIAL ECOLOGICAL DAMAGE)
● - NOT SUITABLE (EXTENSIVE POTENTIAL ECOLOGICAL DAMAGE)
N/A - NOT APPLICABLE

1 VERY HIGH EXCLUDES NEST SITES OF EAGLES, FALCON, BURROWING OWL, FERRUGINOUS HAWK, PRAIRIE DOG TOWNS, (BLACK FOOTED FERRET HABITAT)

2 VERY HIGH EXCLUDES SHARPTAIL, SAGE GROUSE DANCING GROUNDS

3 EXPOSED AREAS DURING DRAW DOWN

4 WEATHER MODIFICATION COULD SUBTLY DEGRADE EXISTING WILDLIFE HABITAT (FACTS ARE UNKNOWN)

DAKOTAS PLANNING TEAM
NOVEMBER 1979

ACTIVITY/ECOSYSTEM SUITABILITY CHART

Figure 3A

CONSTRUCTION OF ROADS, PIPELINES, POWERLINES, & SEISMIC ACTIVITY

	ECOSYSTEMS	1		2		4a		4b		5a		5b		6		7		8		9		10		11	
	CHARACTERISTICS	RIVER BOTTOMS		HARDWOOD DRAWS		UPLAND GRASSLAND (CLAYEY)		UPLAND GRASSLAND (SANDY)		ROLLING GRASSLAND (CLAYEY)		ROLLING GRASSLAND (SANDY)		TERRACES		UPLAND BREAKS		ROCKLAND		RIVER BREAKS		TOE SLOPES		HILLY SCORIA	
P	FLOOD HAZARD	H	⊛	M	⊕	L	○	L	○	VL	○	VL	○	L	○	VL	○	VL	○	VL	○	L	○	VL	○
P	MASS FAILURE HAZARD	L	○	M	⊕	H	⊛	L	○	L	○	L	○	L	○	H	⊛	M	⊕	H	⊛	L	○	L	○
P	SLOPE (IN PERCENT)	0-3	○	3-15	○	15-40	⊕	15-40	⊕	3-15	○	3-15	○	0-3	○	40-70	⊛	15-40	⊕	70+	●	3-15	○	15-40	⊕
P	WATER EROSION HAZARD	VH	⊕	VH	⊕	H	⊕	M	○	H	⊕	M	○	Mod.	○	VH	⊕	H	⊕	VH	⊕	H	⊕	L	○
P	WIND EROSION HAZARD	L	○	M	○	M	○	H	⊕	M	○	H	⊕	L	○	L	○	M	○	L	○	L	○	L	○
B	NON-GAME HABITAT	VH	⊕	VH	⊕	L	○	L	○	L	○	L	○	M	○	M	○	M	○	H	○	L	○	M	○
B	THREATENED OR UNIQUE ANIMAL HABITAT	M	○	L	○	M	○	M	○	VH	⊕	VH	⊕	VH	⊕	M	○	M	○	VH	⊕	H	⊕	H	⊕
B	SMALL GAME HABITAT	H	⊕	VH	⊕	VH	⊕	VH	⊕	H	⊕	H	⊕	L	○	L	○	H	⊕	M	○	L	○	L	○
B	BIG GAME HABITAT	H	⊕	VH	⊛	M	○	M	○	H	⊕	H	⊕	M	○	M	○	M	○	VH	⊛	L	○	M	○
B	FERTILIZER RESPONSE	Mod.	○	Mod	○	L	⊕	L	⊕	Mod.	○	L	⊕	Mod.	○	VL	⊕	L	⊕	VL	⊕	H	○	L	⊕
B	ROOTING ZONE DEPTH	D	N/A	D	N/A	Sh.	N/A	Sh.	N/A	D	N/A	D	N/A	D	N/A	V.Sh	N/A	Sh.	N/A	V.Sh	N/A	D	N/A	Mod.	N/A
B	DOMINANT VEGETATION	TSG	N/A	TS	N/A	GS	N/A	GS	N/A	G	N/A	G	N/A	GS	N/A	S	N/A	GS	N/A	S	N/A	G	N/A	GS	N/A
B	FORAGE PRODUCTIVITY	H	N/A	H	N/A	L	N/A	L	N/A	M	N/A	L	N/A	H	N/A	VL	N/A	M	N/A	VL	N/A	H	N/A	L	N/A
B	VISUAL ATTRACTIVENESS	H	⊕	M	○	H	⊕	H	⊕	L	○	L	○	M	○	VH	⊛	VH	⊛	VH	⊛	L	○	H	⊕
	DEPTH TO WATER TABLE	Sh.	⊕	M	○	UD	○	UD	○	UD	○	UD	○	M	○	UD	○	M	○	UD	○	M	○	UD	○
	PERMEABILITY	MR	○	S	⊕	S	⊕	R	○	S	⊕	R	○	Mod.	○	S	⊕	R	○	S	⊕	S	⊕	R	○
	SURFACE WATER RUNOFF	H	⊕	H	⊕	H	⊕	L	○	H	⊕	L	○	M	○	H	⊕	L	○	H	⊕	H	⊕	L	○
	WATER STORAGE CAPACITY	M	N/A	H	N/A	L	N/A	L	N/A	M	N/A	L	N/A	H	N/A	L	N/A	L	N/A	L	N/A	H	N/A	L	N/A
	PROTECTION FROM WEATHER EXPOSURE	M	○	M	○	L	○	L	○	L	○	L	○	L	○	H	○	L	○	H	○	L	○	L	○
ROLLING PRAIRIE PLANNING UNIT	SUITABILITIES																								
	P = PHYSICAL		⊛		⊕		⊛		⊕		⊕		⊕		○		⊛		⊕		●		⊕		⊕
	B = BIOTIC		⊕		⊛		⊕		⊕		⊕		⊕		⊕		⊛		⊛		⊛		⊕		⊕
	OVERALL		⊛		⊛		⊕		⊕		⊕		⊕		⊕		⊛		⊛		●		⊕		⊕

DAKOTAS PLANNING TEAM 1974

ACTIVITY/ECOSYSTEM SUITABILITY CHART

Figure 3 B

COAL & URANIUM STRIP MINING & RECLAMATION

	ECOSYSTEMS	1		2		4a		4b		5a		5b		6		7		8		9		10		11	
	CHARACTERISTICS	RIVER BOTTOMS		HARDWOOD DRAWS		UPLAND GRASSLAND (CLAYEY)		UPLAND GRASSLAND (SANDY)		ROLLING GRASSLAND (CLAYEY)		ROLLING GRASSLAND (SANDY)		TERRACES		UPLAND BREAKS		ROCKLAND		RIVER BREAKS		TOE SLOPES		HILLY SCORIA	
P	FLOOD HAZARD	H	●	M	⊕	L	○	L	○	VL	○	VL	○	L	○	VL	○	VL	○	VL	○	L	○	VL	○
P	MASS FAILURE HAZARD	L	○	M	○	H	⊕	L	○	L	○	L	○	L	○	H	⊕	M	○	H	⊕	L	○	L	○
P	SLOPE (IN PERCENT)	0-3	○	3-15	○	15-40	⊛	15-40	⊛	3-15	○	3-15	○	0-3	○	40-70	●	15-40	⊛	70+	●	3-15	○	15-40	⊛
P	WATER EROSION HAZARD	VH	⊛	VH	⊛	H	⊕	M	⊕	H	⊕	M	⊕	Mod.	⊕	VH	⊛	H	⊕	VH	⊛	H	⊕	L	○
P	WIND EROSION HAZARD	L	○	M	○	M	○	H	⊕	M	○	H	⊕	L	○	L	○	M	○	L	○	L	○	L	○
B	NON-GAME HABITAT	VH	⊛	VH	⊛	L	○	L	○	L	○	L	○	M	⊕	M	⊕	M	⊕	H	⊛	L	○	M	⊕
B	THREATENED OR UNIQUE ANIMAL HABITAT	M	⊛	L	⊕	M	⊛	M	⊛	VH	●	VH	●	VH	●	M	⊛	M	⊛	VH	●	H	●	H	●
B	SMALL GAME HABITAT	H	⊛	VH	●	VH	●	VH	●	H	⊛	H	⊛	L	○	L	○	H	⊛	M	⊕	L	○	L	○
B	BIG GAME HABITAT	H	●	VH	●	M	⊛	M	⊛	H	●	H	●	M	⊛	M	⊛	M	⊛	VH	●	L	⊕	M	⊛
B	FERTILIZER RESPONSE	Mod.	○	Mod.	○	L	⊕	L	⊕	Mod.	○	L	○	Mod.	○	VL	⊛	L	○	VL	⊛	H	○	L	⊕
B	ROOTING ZONE DEPTH	D	○	D	○	Sh.	⊕	Sh.	⊕	D	○	D	○	D	○	V.Sh.	●	Sh.	⊕	V.Sh.	●	D	○	Mod.	○
B	DOMINANT VEGETATION	TSG	N/A	TS	N/A	GS	N/A	GS	N/A	G	N/A	G	N/A	GS	N/A	S	N/A	GS	N/A	S	N/A	G	N/A	GS	N/A
B	FORAGE PRODUCTIVITY	H	⊕	H	⊕	L	⊛	L	⊛	M	⊕	L	⊛	H	⊕	VL	●	M	⊕	VL	●	H	⊕	L	⊛
B	VISUAL ATTRACTIVENESS	H	●	M	●	H	●	H	●	L	⊕	L	⊕	M	⊕	VH	●	VH	●	VH	●	L	⊕	H	●
	DEPTH TO WATER TABLE	Sh.	●	M	⊕	UD	○	UD	○	UD	○	UD	○	M	⊕	UD	○	M	⊕	UD	○	M	⊕	UD	○
	PERMEABILITY	M.R	○	S	⊕	S	⊕	R	○	S	⊕	R	○	Mod.	○	S	⊕	R	○	S	⊕	S	⊕	R	○
	SURFACE WATER RUNOFF	H	⊕	H	⊕	H	⊕	L	○	H	⊕	L	○	M	○	H	⊕	L	○	H	⊕	H	⊕	L	○
	WATER STORAGE CAPACITY	M	○	H	⊕	L	⊛	L	⊛	M	○	L	⊛	H	⊕	L	⊛	L	⊛	L	⊛	H	⊕	L	⊛
	PROTECTION FROM WEATHER EXPOSURE	M	⊕	M	⊕	L	○	L	○	L	○	L	○	L	○	H	●	L	○	H	●	L	○	L	○
ROLLING	SUITABILITIES																								
PRAIRIE	P = PHYSICAL		●		⊛		⊛		⊛		⊕		⊕		⊕		●		⊛		●		⊕		⊛
PLANNING	B = BIOTIC		●		●		●		●		●		●		●		●		●		●		●		●
UNIT	OVERALL		●		●		●		●		●		●		●		●		●		●		●		●

DAKOTAS PLANNING TEAM 1974

PHYSICAL[1] SUITABILITY SUMMARY

Figure 4

ECOSYSTEM ACTIVITY	1	2	4a	4b	5a	5b	6	7	8	9	10	11
CANALS	⊛	⊛	●	⊛	⊕	○	○	●	⊛	●	⊕	⊛
COAL & URANIUM STRIP MINING & RECLAMATION	●	⊛	⊛	⊛	⊕	⊕	⊕	●	⊛	●	⊕	⊛
COMMON VARIETY MINERAL MATERIALS	○	○	⊕	○	○	○	○	⊛	○	●	○	○
CONSTRUCTION OF ROADS, PIPELINES, POWERLINES, & SEISMIC ACTIVITY	⊛	⊕	⊛	⊕	⊕	⊕	○	⊛	⊕	●	⊕	⊕
HEAVY VEHICLE — OFF ROAD USE	⊕	⊕	⊕	⊕	⊕	⊕	○	⊛	⊕	●	⊕	⊕
IRRIGATION FOR CROP	⊛	⊛	●	●	⊕	⊛	○	●	●	●	⊕	●
LARGE IMPOUNDMENTS	⊛	⊛	⊛	⊕	⊕	⊕	○	⊛	⊕	⊛	⊕	○
MECHANICALLY AIDED FORAGE PRODUCTION FOR GRAZING	⊛	⊛	⊛	⊛	⊕	⊛	○	●	⊛	●	⊕	⊛
NATURAL FORAGE PRODUCTION FOR GRAZING	⊛	⊛	⊕	⊕	⊕	⊕	○	⊛	⊕	●	⊕	⊕
OIL & GAS	⊛	⊕	⊛	⊕	⊕	⊕	○	⊛	⊕	●	⊕	⊕
RECREATION — PRIMITIVE	○	○	○	○	○	○	○	○	○	○	○	○
RECREATION - DISPERSED	⊕	⊕	○	○	○	○	○	⊕	○	⊛	○	○
RECREATION - SEMI - DEVELOPED	⊛	⊕	⊛	⊛	⊕	⊕	○	●	⊛	●	⊕	⊛
RECREATION - DEVELOPED	●	⊛	⊛	⊛	⊕	⊕	○	●	⊛	●	⊕	⊛
SMALL IMPOUNDMENTS	●	⊛	⊕	⊕	⊕	○	○	⊛	⊕	●	⊕	⊕
TREE HARVEST	⊛	⊛	⊕	⊕	⊕	⊕	○	⊛	⊕	●	⊕	○
WATER SYSTEMS	⊕	⊕	⊕	⊕	○	○	○	⊛	⊕	●	○	⊕
WEATHER MODIFICATION	⊕	⊕	⊛	○	○	○	○	⊛	⊕	⊛	○	○
FIRE MANAGEMENT (BURNING)	⊛	⊛	⊕	⊛	⊕	⊛	○	⊛	⊕	⊛	⊕	⊕

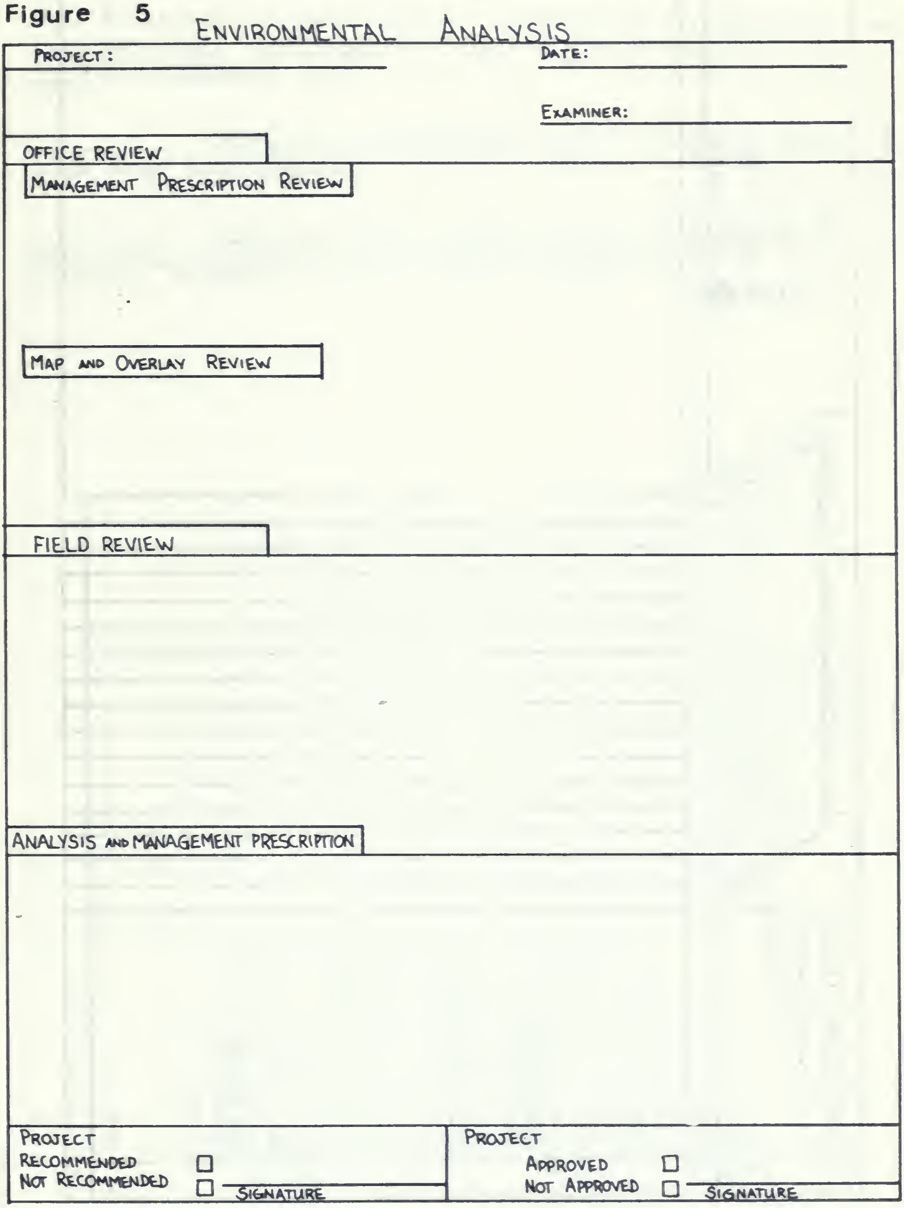
1: WATER EROSION HAZARD FOR DISTURBED SOIL; WIND EROSION HAZARD; MASS FAILURE HAZARD; FLOOD HAZARD; SLOPE

2: PRESERVATION OF AREAS, LAND ADJUSTMENT, HABITAT MANAGEMENT — NO RATING NEEDED BY ECOSYSTEM

○ = SUITABLE
⊕ = MODERATELY SUITABLE
⊛ = LOW SUITABILITY
● = NOT SUITABLE

ROLLING PRAIRIE PLANNING UNIT
DAKOTAS PLANNING TEAM
APRIL 1974

Figure 5



ENVIRONMENTAL ANALYSIS

PROJECT:

DATE:

EXAMINER:

OFFICE REVIEW

MANAGEMENT PRESCRIPTION REVIEW

MAP AND OVERLAY REVIEW

FIELD REVIEW

ANALYSIS AND MANAGEMENT PRESCRIPTION

PROJECT
RECOMMENDED ☐
NOT RECOMMENDED ☐
SIGNATURE

PROJECT
APPROVED ☐
NOT APPROVED ☐
SIGNATURE

Figure 6

Ecosystem Suitability Chart
Little Missouri National Grasslands
Planning Unit
Project :
Activity :

○ Suitable
⊕ Medium Suitability
⊗ Low Suitability
● Not Suitable

	CHARACTERISTICS	1	2	3	4	4A	4B	5	5A	5B	6	7	8	9	10	11	
	Ecosystem	River Bottom	Hardwood Draw	Ponderosa Pine	Upland Grassland	Upland Grassland (Clayey)	Upland Grassland (Sandy)	Rolling Grassland	Rolling Grassland (Clayey)	Rolling Grassland (Sandy)	Terraces	Upland Breaks	Rockland	River Breaks	Toe Slopes	Hilly Scoria	Cumulative Effects
Physical	Flood Hazard																
	Mass Failure Hazard																
	Slope																
	Water Erosion Hazard																
	Wind Erosion Hazard																
Biotic	Non-Game Habitat																
	Threatened/Unique Animal Habitat																
	Small Game Habitat																
	Big Game Habitat																
	Fertilizer Response																
	Rooting Zone Depth																
	Dominant Vegetation																
	Forage Productivity																
Soil/Water	Depth to Water Table																
	Permeability																
	Surface Water Run-Off																
	Water Storage Capacity																
	Protection from Weather Exposure																
	Visual																
Cumulative Effects																	

Remarks

and multiple-use management based upon ecological information.

LITERATURE CITED

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3, ________. Rolling Prairie Planning Unit, Considerations for Future Management; Environmental Statement Draft. Billings, Montana. 216 p. December 1974.

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THE TOPOGRAPHIC AND EDAPHIC DISTRIBUTION OF SEVERAL PLANT COMMUNITIES OF WARM AND COOL SEASON SPECIES IN SOUTHEASTERN MONTANA

Melvin S. Morris and Robert E. Lovegrove*

INTRODUCTION

The opportunity to observe and study the environmental factors controlling the distribution of a number of distinctive plant communities on the landscape within a limited area is seldom obtainable. The study location west of Ft. Howes with a variety of geological materials and topography provided the setting. The following six microcommunities are easily distinguished: 1) *Calamovilfa longifolia-Andropogon scoparius*, 2) *Andropogon scoparius-Carex filifolia*, 3) *Festuca idahoensis-Stipa comata*, 4) *Stipa comata*-Prairie junegrass, 5) *Stipa viridula-Agropyron smithii*, 6) *Agropyron spicatum*-Prairie junegrass. Relatively narrow ecotones separate the stand types or plant communities on the limited acreage involved. Sand reedgrass and little bluestem are the two warm season species while the other dominant grasses and sedges grow more rapidly, flower and mature in the cooler portion of the growing season. Bluebunch wheatgrass and particularly Idaho fescue are more typical of the foothill and mountain grasslands of the Rockies than the other cool season species. Blue grama is a minor species in the study area.

LOCATION OF THE STUDY AREA

The study site is located at the head of Cow Creek about six miles southwest of Fort Howes, Montana, on the Fort Howes Ranger District of the Custer National Forest in the SW 1/4 of S18 and the NW 1/4 of S19, R45E, T6S, M.P.M. A major portion of the area was fenced in 1966.

CLIMATE

The climatic characteristics of the site may be inferred from the available data from Weather Bureau records of established stations at Birney and Sonnette and seasonal fire weather data collected from May through September at Fort Howes. These data are of limited value because of elevational limitation. Birney is 1000 feet lower, Sonnette is 300 feet lower and Fort Howes is 900 feet lower in elevation.

In Table 1 monthly precipitation summary data is presented for Birney (1955-1960) and Sonnette (1951-1960). Figure 1 contains the growing season precipitation for Fort Howes. It is arranged in ten day periods from May 1 - September 20. The seasonal patterns are applicable to the study site. December to March are relatively dry months a contribute little to storage for spring growth. April to August should be significant months of moisture supply. May and June are especially important for both cool and warm season species. The totals for the months of April-August are in excess of sixty-nine percent of the annual precipitation.

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Interpolation of yearly totals of the two stations to the study area represents some risk. However, the elevation difference would suggest that the site should receive at least two to three inches more precipitation. Elsewhere, Dightman (1) indicates that at elevations above 3,900 feet in the Powder River Area, precipitation averaged 17 inches a year for a 22 year period.

Seasonal moisture for the Fort Howes station indicates the moisture supply relative to the study site was high in May, 1965, moderately low in 1966, June was about average in 1965 and high in 1966, July was above average in 1965 and low in 1966, August was low in both years, September was high in both years. In general, the precipitation record for the study years represents neither an abnormally wet or dry situation relative to measuring the rate of soil moisture use by the various plant communities or their characterizing species.

TOPOGRAPHY AND GEOLOGY

A major rise with long smooth south facing slope, a narrow east and west bearing crest and a concave north facing slope dominates the area. See Figure 2. A swale draining to the east and a series of low rounded ridges to north of the major rise completes the relief on the area.

The principal effect of topography on soil and vegetation are first to create a cooler environment on the north facing slope and a somewhat warmer one on the south facing slope and the crests of the low rises. Also, runoff would be facilitated if cover is reduced or the soil's permeability is low as it may be on the low rises because of the high clay content. In general topographic influences are secondary to other factors.

Geology as it contributes to the variety of soils developed is a major intrinsic factor. The area is within the Tongue River member of the Fort Union Formation and consists of nearly level bedded, weakly consolidated sandstones, siltstones and shales. In some places coal seams of variable thickness may occur. Scoria or porcellanite derived from burning coal seams is not present in the study area.

SOILS

The influence of geology and to a lesser extent topography is apparent in the array of soils. The highest elevation contains remnants of a sandstone cap and a limited area of the Ocean Lake loamy sand (see Figure 2 and Table 2). It is a regosol with an A, AC, IIC1, IIC2 profile. It has considerable porosity and limited water holding capacity, the A horizon is 12 inches thick.

The next soil series below is Remmit sandy loam. It is derived in places from sandstone and has a normal profile. The A horizon is approximately 12 inches thick. It has a B1 and C1 horizon. It retains more moisture than the Ocean Lake series.

Table 1. Average monthly and annual precipitation data for Birney and Sonnette, Montana, for record period. Fort Howes data for May-August for two years indicated data in inches.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Ann.
Birney 10 mi,w 1955-60	.14	.43	.29	1.30	1.93	2.57	1.10	1.05	.43	.94	.87	.39	11.44
Sonnette 24 mi,ne 1951-60	.25	.35	.42	.94	2.13	2.22	1.39	1.16	.71	.90	.63	.25	11.35
Ft. Howes 6 mi, se 1965-66				1965	2.35	2.19	1.52	.59					
				1966	1.66	3.03	.86	.78					

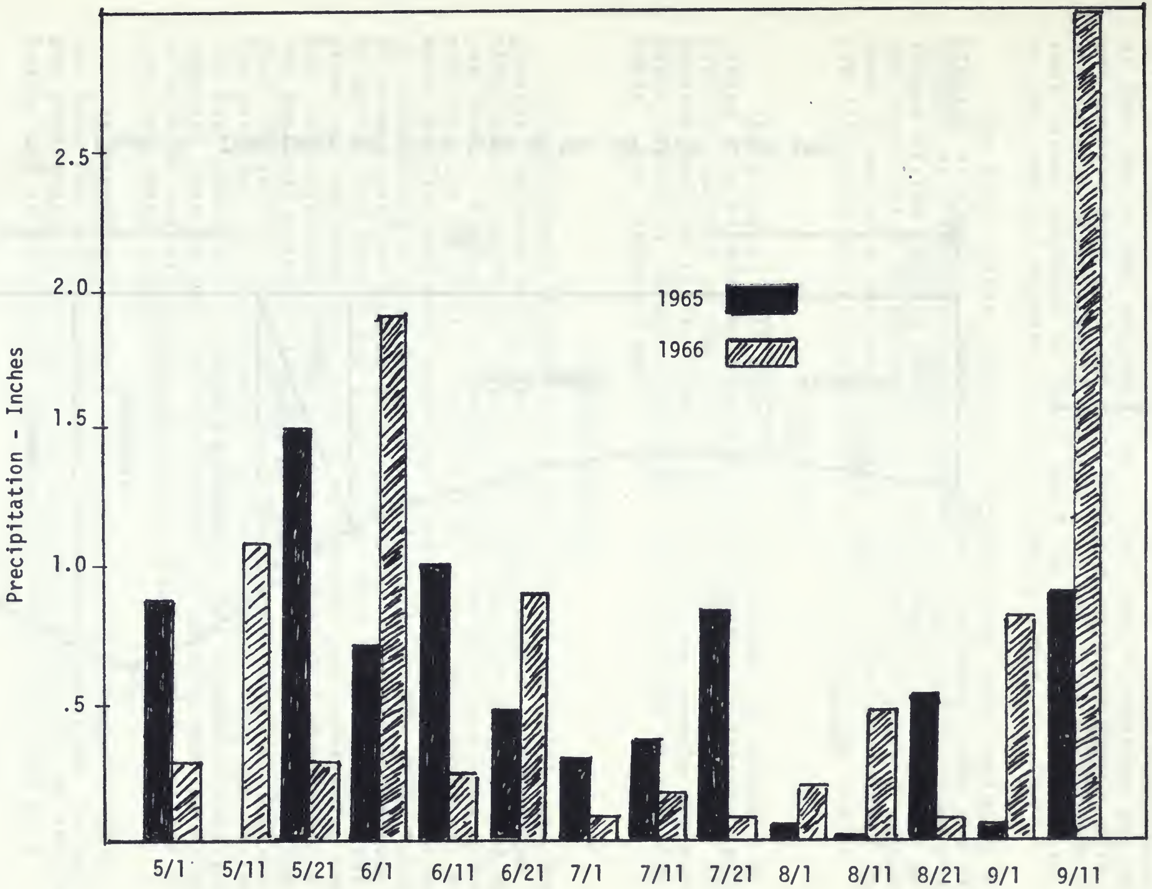

Figure 1. May-September precipitation in inches per 10 day period preceding each date above. Ft. Howes Ranger Station 10 miles east of study site. 1965 and 1966.

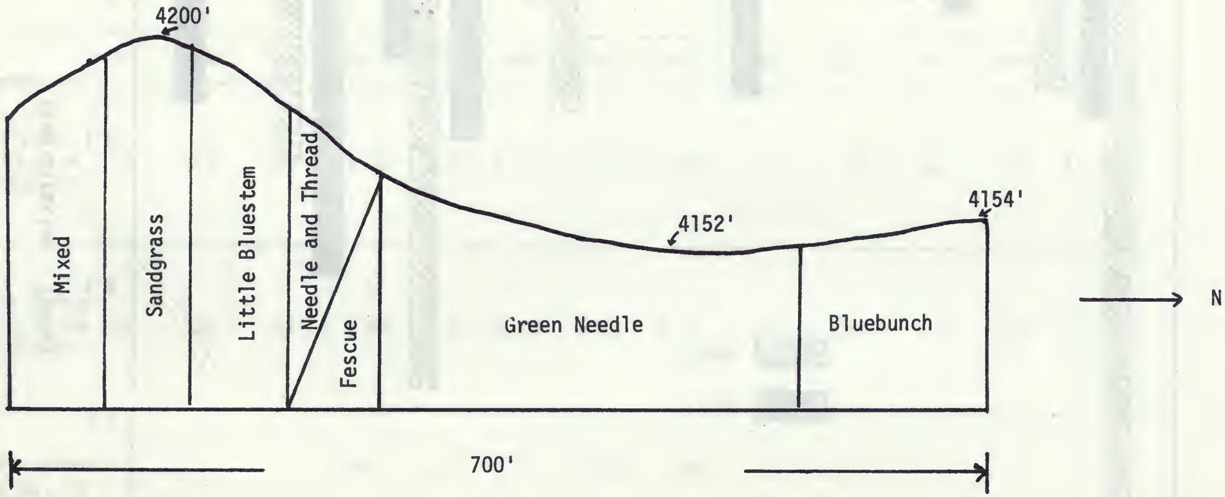

Figure 2. Topography and stand type on the Cow Creek study area.

The next two series are adjacent to each other at the same elevation. One is classified as a Remmit fine sandy loam to distinguish it from the previous series because of the more moderate slope and higher clay content in the first foot. It has a normal profile derived from upslope material. The adjacent soil is difficult to classify. In Table 2, it has been designated Vona but is not typically so. The A and B horizons are sandy but contain more silt and clay than the adjacent Remmit soil. The horizon below identified as a C in the table is not the original parent material of the A and B horizons. Texturally it is a clay loam and appears to be an altered shale.

The soil series occupying the swale has been variously named Promise or Thurlow. However, the upper horizons lacks the silt content of a typical Thurlow and the entire profile lacks massiveness of the Promise series. The cracking of the surface and the association of the vegetation with other locations suggests that it may be a marginal Promise (Kyle). The low rounded knolls are lithosols and are considered to be in the Midway series.

VEGETATION

The array of soil types on the topography is strongly associated with either the characterizing species of grasses such as prairie sandreed on the hill crest or the dominant species of grasses such as little bluestem, Idaho fescue, needle and thread, green needle or western wheatgrass and blue bunch on the other soils. See Figures 2 and 3.

GRAZING HISTORY

Southeastern Montana has a long history of cattle and horse grazing, perhaps dating back to at least 1880. Little or no sheep use is known for a large area between Otter Creek and Tongue River. Patterns of grazing appear to have developed under moderate use by cattle. South facing slopes and swales are the most heavily used with resulting loss in dominance by bluebunch on southfacing slopes and green needlegrass in the grassy swales. In some locations ridges in grassland may have been overgrazed by horses and cattle and a subsequent loss of bluebunch wheatgrass and replaced by a variety of grasses and forbs. The tendency for livestock to avoid heavy use of north slopes and possibly the seasonal palatability of little bluestem and Idaho fescue plus the general moderate use of the general area has favored the survival of these species in the abundance they now present. The high abundance of green needlegrass and bluebunch wheatgrass suggests that in spite of the history of grazing and the present of working corrals to the northeast, the vegetation appears to have been near climax in 1965.

It should be reported that the principal change by 1974 has been the shift in abundance from green needlegrass to western wheatgrass in the swale and an increase in phlox on the low knolls and is attributed to unexpected use of the area as a

Table 2. Soil series, textural character and 15A moisture values associated with the several plant communities.

Stand Type	Soil Series	Depth in.	Separates Sand %	Separates Silt %	Separates Clay %	Moist. at 15A %	Soil Profile and Textural Class
Sand reed-grass	Ocean Lake	0-6	79.7	12.9	7.4	2.9	A, 0-12 in.
		6-12	78.4	11.9	9.7	2.4	loamy sand
		12-18	79.9	12.9	7.2	3.0	
		18-24	75.3	14.8	9.9	3.8	C, 12+ in.
		24-30	75.4	15.3	9.3	3.8	sandy loam
		30-36	72.9	16.1	11.0	4.0	
Little blue-stem	Remmit	0-6	70.9	17.7	11.4	5.0	A, 0-7 in.
		6-12	75.1	12.2	12.7	4.9	sandy loam
		12-18	69.1	17.9	14.0	5.3	AB, 7-12 in.
		18-24	60.1	20.5	19.4	5.4	sandy loam
		24-30	61.2	20.0	18.8	5.2	B, 12+ in.
		30-36	59.4	22.3	18.3	6.3	sandy loam
Idaho fescue	Vona*	0-6	67.7	17.4	14.9	5.2	A, 0-6 in, sandy loam
		6-12	52.6	27.9	19.5	10.0	B, 6-12 in, sandy loam
		12-18	30.1	44.5	25.4	14.2	C, 12+ in, clay loam
		18-24	15.2	49.7	35.1	17.5	
Needle-and Thread	Remmit	0-6	74.0	9.2	16.8	5.2	A, 0-10 in.
		6-12	64.5	18.0	17.5	6.9	sandy loam
		12-18	64.2	19.5	16.3	5.8	
		18-24	64.3	18.7	17.0	5.8	B, 10+ in.
		24-30	50.8			6.6	sandy loam
Green needle-grass	Thurlow	0-6	31.2	33.4	35.4	11.2	A, 0-8 in, clay loam
		6-12	26.1	31.6	42.3	14.3	B, 8-20 in, clay loam
		12-18	28.5	35.2	36.3	15.2	C, 20+ in, loam
		18-24	43.2	30.7	26.1	12.7	
Bluebunch wheat-grass	Midway	0-6	20.3	25.5	54.2	18.8	A, 0-8 in.
		6-12	15.1	19.3	65.6	18.6	clay
		12-18	9.2	15.9	74.9	18.7	C, 8+ in.
		18-24	8.6	17.7	73.7	21.0	clay

* Idaho fescue associated with Vona elsewhere. Here A and B horizons derive from upslope materials (sandstone), C derived from siltstone weathered in place.

result of the fencing. Other differences in vegetation between 1965 and 1974 are mainly due to location of sample lines. It was not anticipated to resample and no permanent stakes were placed. The boundary between the sand reedgrass stand and the little bluestem stand is not well defined. The 1974 sampling attempted to limit the vegetation analysis to the crest of the hill where sand reedgrass was distinctly dominant. The needle and thread grass type south of the hill crest was no included because of the apparent grazing history.

FIRE HISTORY

An extensive fire occurred on the Fort Howes Ranger District in the summer of 1966. Some twenty thousand acres were burned and extended through a variety of vegetation types. Little apparent effects in the grassland could be seen in 1974.

VEGETATION ANALYSIS

The stand types were defined by the characterizing species of grass; that is, physiognomy or abundance. The boundaries were established by control with steel tape, abney level and compass. The most difficult boundary was the one separating the sand reedgrass type from little bluestem type. The total area sample is approximately five acres. See Figure 3.

Twenty five square foot plots were located along a line through the center of each type. Plots were taken at ten foot intervals. Canopy coverage estimates from each plot frame were facilitated by subdividing the frame into 50, 30, 20, 10, and 2 percent units. In 1974, 20 plots were used per stand. Frequency percent and coverage percent were calculated from the initial observations. The 1965 data are presented in Table 3 and the 1974 data in Table 4.

On the basis of frequency and abundance the characterizing species in each stand type has either high frequency or coverage values or both. It is of interest to note that for the green needlegrass stand type, western wheatgrass has a higher frequency than green needlegrass but a lower abundance in the 1965 analysis and perhaps why it became more abundant due to the grazing influence by 1974. Of the dominant species little bluestem and sand reedgrass appear to be the most restricted (two stand types). Prairie junegrass, a distinct subdominant, is widely distributed and has both high frequency and coverage in several types. It could be used as one of the characterizing species in the bluebunch wheatgrass type.

Comparisons of species abundance between 1965 and 1974 need some examination before any final characterization of the sand types are made or the significance of the abundance of a species is suggested. As noted previously the unexpected access of grazing animals to the enclosure and the evident trampling over much of the bluebunch wheatgrass stand has been responsible for the loss of green needle grass in the swale area and possibly the increase in phlox in the bluebunch wheatgrass stand. The half-shrubs, snakeweed and fringed sage have also increased in the bluebunch wheatgrass stand. From a general examination it appears that the other stand types may differ between years more from problems associated with sampling and estimating than from grazing.

Several questions of ecological importance need to be considered and answered if possible. The warm season dominants, little bluestem and sand reedgrass appear to be more associated with soil moisture than soil temperature. They occupy the coarser soils on the coolest slopes. Blue grama a warm season subdominant occupies all sites in small clumps. The cool season grasses and sedges range over a variety of soils and moisture conditions. Prairie junegrass is widely distributed except for the Idaho fescue stand type. It is next in importance to the dominant grass in two of the stand types; needle and thread type and bluebunch wheatgrass type. One is a sandy soil and the other a clayey soil.

In general where soil moisture may be a limiting factor in the distribution of species, species like little bluestem and sand reedgrass will be on coarse soils and have their extension into a drier climatic zone where topography (exposure) modifies temperature effects. Dominance achieved finally by being able to use deep soil moisture distribution.

Species such as green needlegrass and western wheatgrass are more typically associated with clayey soils and are probably moisture limited but have growth rates and plant size which make them highly adapted to clay soils.

Needle and thread grass shows a high association with coarser soils at this location. Elsewhere it may have a wider soil adaptability. This may be due to its ability to resist moderately heavy seasonal grazing as well as to be able to regenerate readily.

Idaho fescue shows considerable adaptability on the basis of its occurrence here. There are perhaps two conditions other than ecotypic responsible for the extension of the range of this species, the association with cooler north exposures and the structure of the soil profile favoring retention of moisture in the upper portion of the profile. Bluebunch wheatgrass growing on a variety of soils either because of their coarse texture or the tendency of the soil to fracture (lithosols) thus providing better moisture penetration and enabling it to compete with a wide variety of species.

The distribution pattern of C. filifolia is as expected. It is commonly abundant on coarser soils or relatively immature soils, such as the Midway series which has considerable clay.

In general, the secondary species especially the forbs appear to be less clearly associated with soil or site. *Phlox alyssifolia* is on immature sandy or clayey soil. *Senecio cana* is on coarse sand, *Campandula rotundifolia* is associated with a sandy site but may also characterize a dependence on little bluestem. Yucca is associated with coarse soil at this location. Rose while more common on sandy, yet appears on the heavy textured soil in the swale. It should be added that if the sampling had been more intensive the information on the secondary species could have been more informative.

OTHER PLANT INFORMATION

Root systems were exposed in the process of obtaining soil

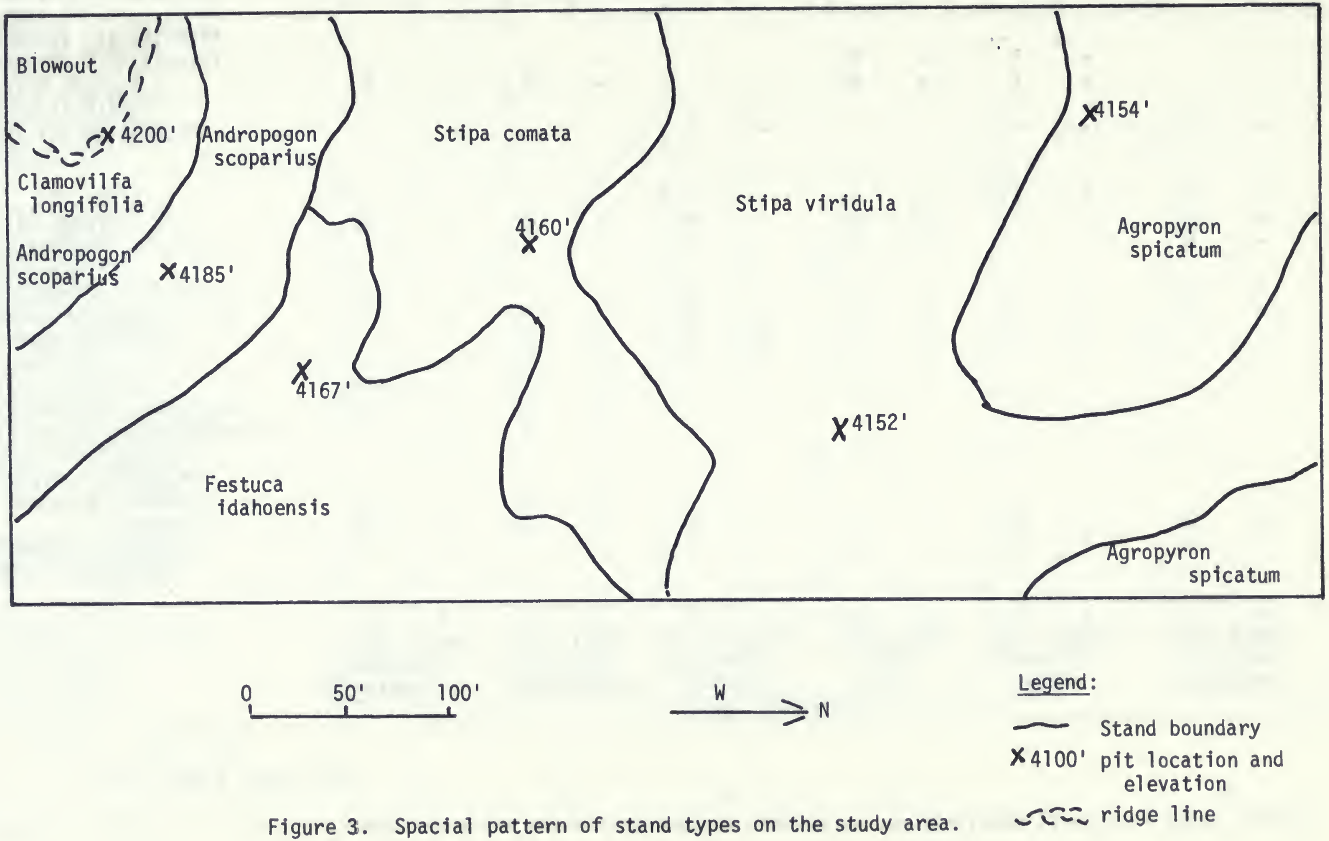

Figure 3. Spacial pattern of stand types on the study area.

Table 3. Frequency percent and canopy coverage percent of various species on the Cow Creek study area (1965) based on 25 square foot plots.

	PLANT COMMUNITIES											
	Calamovilfa longifolia		Andropogon scoparius		Festuca idahoensis		Stipa comata		Stipa viridula		Agropyron spicatum	
	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %
Grasses and Sedges												
Agropyron smithii	12	*			24	1	28	*	68	2	60	3
" spicatum	16	1	32	2	40	3			36	3	80	10
Andropogon scoparius	72	14	92	29								
Aristida longiseta												
Bouteloua gracilis		12	1				4	*				
Calamagrostis montanensis												
Calamovilfa longifolia	56	2	20	1	4	*						
Carex filifolia	60	9	40	4			12	1				
Carex spp.	8	*	56	3	72	32	?	3	?	1	?	2
Festuca idahoensis			8	*	96	32	4	*	8	2		
Koeleria cristata	44	1	32	1	24	1	80	7	60	5	76	5
Muhlenbergia cuspidata	12	1			12	*	4	*			12	2
Poa pratensis												
" secunda							4	*	1	*	4	*
Stipa comata	36	2	12	1	36	1	92	20			4	*
" viridula					4	*	4	*	60	9	28	2
Forbs												
Achillea millefolium					8	*			8	*	8	*
Agoseris glauca												
Allium textile	8	*	4	*			4	*	4	*		
Antennaria parvifolia							24	2	4	*		
Ambrosia psilostachya												
Arabis sp.												
Artemisia ludoviciana			4	*							8	*
Aster falcatus	8	1							16	1	4	*
Astragalus gilviflorus												
" missouriensis	8	*			8	*					4	*

(Continued next page)

Table 3. continued

	Calamovilfa longifolia		Andropogon scoparius		Festuca idahoensis		Stipa comata		Stipa viridula		Agropyron spicatum	
	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %
Campanula rotundifolia												
Cerastium arvense									12	*		
Chrysopsis villosa												
Cirsium undulatum			8	1	4	*						
Comandra umbellata					12	*						
Echinacea pallida					4	*			8	*	12	*
Erigeron spp.												
Gaura coccinea	28	2	12	*	8	*			12	*		
Grindelia squarrosa												
Leucocrinum montanum												
Linum perenne	4	*	42	1	4	1	20	*	4	*	4	*
Lithospermum ruderale	8	*	20	*	20	1	16	*			12	*1
Oxytropis spp.									4	*		
Phlox alyssifolia											16	1
" hoodii	24	2	4	*			28	1	44	4	56	4
Psoralea argophylla			8	*	24	*	4	*	8	*	8	*
Senecio cana	16	1										
Solidago missouriensis			4	*								
Sphaeralcea coccinea							16	*	32	*	8	*
Taraxicum officinale					4	*	8	*	4	*		
Zigadenus venenosus							12	*				
Shrubs and Half-Shrubs												
Artemisia cana	12	1	4	*	44	5	12	*	36	2	4	2
" frigida	12	*	8	*	28	1	64	3	20	2	20	1
Eurotia lanata												
Gutierrezia sarothrae			4	*	4	*	4	*	8	*	16	*
Opuntia spp.							8	*	4	*		
Rosa arkansana	36	2	28	4	12	*			12	1		
Yucca glauca	16	3	4	2								
Misc. Species, mostly ann.	X	1	X	1	X	4						
Total Cover		44		55		53		40		37		34

*less than ½ percent

(End of Table 3)

Table 4. Frequency percent and canopy coverage percent of various species on the Cow Creek study area, 7/17/74.

Average of 20 square foot plots.

	PLANT COMMUNITIES											
	Calamovilfa longifolia		Andropogon scoparius		Festuca idahoensis		Stipa comata		Stipa viridula		Agropyron spicatum	
	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %
Grasses and Sedges												
Agropyron smithii	20	*			75	3	65	4	100	10	15	*
" spicatum			15	1	5	*	25	2			80	6
Andropogon scoparius	5	1	100	25								
Aristida longiseta					5	*						
Bouteloua gracilis	15	1	15	*	15	1	15	1	20	1	5	1
Calamagrostis montanensis[1]	30	*	5	*			15	*	5	*	40	1
Carex filifolia	85	5	40	2			5	*			15	*
Carex spp.	50	2	80	2	85	3	90	6	90	4	10	*
Festuca idahoensis			20	1	90	18			5	1		
Koeleria cristata	45	2	35	1	20	*	70	3	45	1	60	4
Muhlenbergia cuspidata			5	*	20	2	5	1	5	1	25	2
Poa pratensis							5	*				
" secunda			5	*	30	1	5	*	15	*	10	*
Stipa comata	65	7	40	1	75	5	100	10			15	1
" viridula			5	*	10	1	10	*	65	4	35	1
Forbs												
Achillea millefolium			15	1	10	*	35	1	95	5	6	2
Agoseris glauca									5	*		
Allium textile					5	*						
Antennaria parvifolia							10	*				
Ambrosia psilostachya	20	1										
Arabis sp.					15	*	5	*				
Artemisia ludoviciana					10	*						
Aster falcatus					5	*	10	*			55	1
Astragalus gilviflorus											15	*
" missouriensis			25	*								

[1] Calamouilfa longifolia omitted following Calamogrostis. Values for first two stands are 100 13 and 20 and * respectively.

(Continued next page)

Table 4. continued

	Calamovilfa longifolia		Andropogon scoparius		Festuca idahoensis		Stipa comata		Stipa viridula		Agropyron spicatum	
	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %	Freq. %	Cover %
Campanula rotundifolia			10	*								
Cerastium arvense			45	1	25	*	5	*	5	*	15	*
Chrysopsis villosa	5	*										
Cirsium undulatum							10	1				
Comandra umbellata			65	2	10	1						
Echinacea pallida							5	1	5	*	60	1
Erigeron spp.							15	1				
Gaura coccinea											10	*
Grindelia squarrosa							5	*				
Leucocrinum montanum					5	*	15	*	5	*	15	*
Linum perenne			10	*							20	1
Lithospermum ruderale	5	*										
Oxytropis spp.			15	1								
Phlox alyssifolia											20	*
" hoodii			20	1	5	*	50	3	15	1	100	12
Psoralea argophylla	45	1	25	*	10	*			5	1	45	1
Senecio cana			10	*								
Solidago missouriensis			10	1							10	1
Sphaeralcea coccinea					15	1			50	1		
Taraxicum officinale			5	*			5	*	10	*		
Zigadenus venenosus							5	*				
Shrubs and Half-Shrubs												
Artemisia cana					20	5	5	*	5	*	10	*
" frigida					40	3	35	3	30	1	25	1
Eurotia lanata												
Gutierrezia sarothrae							15	2	15	1	50	4
Opuntia spp.					10	*	15	1				
Rosa arkansana	15	1										
Yucca glauca			5	1								
Misc. Species, mostly ann.		1		?		2						
Total Cover		34		40		46		41		32		44

*less than ½ percent

(End of Table 4)

moisture samples from the pits. Figure 4 shows the generalized root systems. The sand reedgrass and little bluestem patterns are similar and are characteristic of the species and as expected for the deep sandy soils. The root profile under Idaho fescue while somewhat as expected, does reflect a soil structural influence. The needle and thread root profile is only slightly better developed. The root system for the mixed green needlegrass - western wheatgrass stand shows an intermediate development. The bluebunch wheatgrass stand root profile is relatively shallow.. When these profiles are related to soil moisture distribution patterns and their depletion a clearer picture of the function of both plant and soil have in the geographic of vegetation.

Notes on the phenology of some of the species for 1965 are reported in Table 5. Threadleaf sedge is one of the earliest species based on flowering observation. Bluebunch wheatgrass, Idaho fescue, prairie junegrass, and needle and thread grass are more typical of the cool season species, and show development somewhat earlier than western wheatgrass and green needlegrass. The warm season grasses are later in reaching lowering and seed development as indicated in the data. The response to moisture is reflected in the drying of leaves. The warm season grasses are later and probably reflect a slower rate of early moisture utilization.

SOIL MOISTURE ANALYSIS

The relative abundance or dominance of certain warm season species in certain stand types and cool season species in others and their corresponding functional periods should be reflected in soil moisture distribution and use. Likewise the relative effect of soil texture and structure should be apparent in the interaction of plant species and soil.

The soil moisture data has some restrictions for this purpose. Soil moisture data is expressed as percent of oven dry weight. The collections were limited to the dates indicated for 1965 and in 1966. The distance to collect samples for this determination was a problem. While a greater effort was made in 1966 by use of personnel at Fort Howes, the last sample date was lost as a result of a cloud burst and subsequent flooding of the pits. An attempt to secure bulk density samples resulted in data which did not characterize the heavy textured soils. Consequently, the moisture data was not coverted to inches of moisture. The difference expressed between the 15 atmosphere reading (non-available) water and the actual percent moisture is equal to the available moisture. This data is contained in Table 6.

The 1965 data shows that soil moisture while declining was available through mid-August in both the sand reedgrass soil and the little bluestem stands at all depths but did not become unavailable. In 1965, the soil moisture in the sand reedgrass stand was unavailable by August 2 and had not reached this level in the little bluestem soils at the last measurement on September 1. Interpretation of the data suggests that the sand reedgrass site was the drier of the two and had less available water. Initial supply (wind effect) evaporation and transpiration (higher air temperature) and more rapid growth may all be involved.

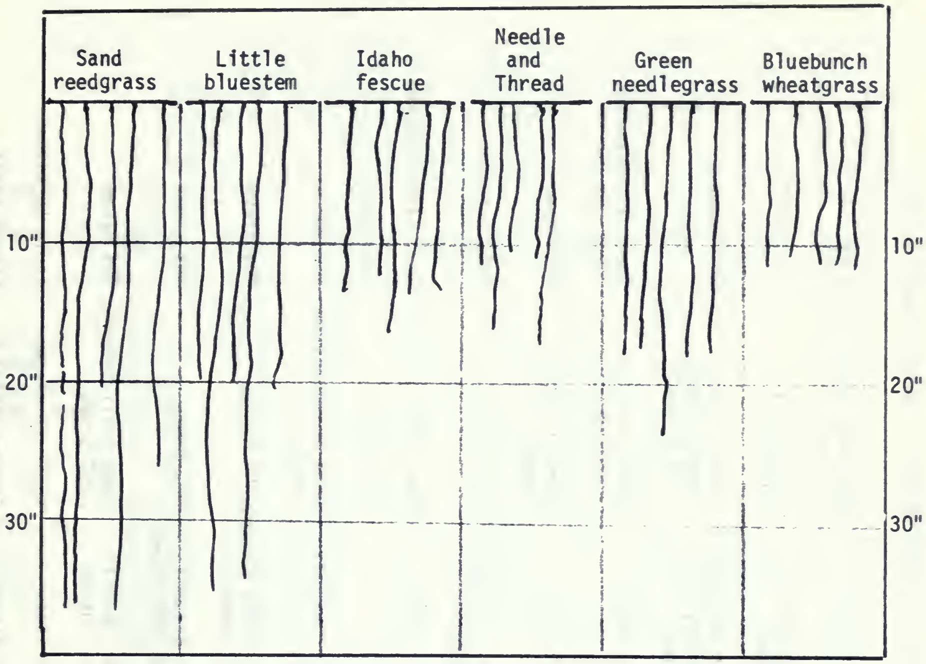

Figure 4. Relative rooting pattern under each of the six stand types. 1965 observations.

Table 5. General phenological observations at soil moisture sampling dates, 1965.

	June 17	July 15	Aug. 12	Sept. 13
Agropyron smithii	Beginning to head	Beginning to head	Seed ripe, 95% green	75% green
Agropyron spicatum	Full bloom	Seed ripe, dissemin, 10% brown	Seed disseminated, leaves 90% brown	90% brown
Andropogon scoparius	Leaf stage	Leaf stage	Seed in dough, stem red	Seed disseminating, stem purple
Boutelova gracilis	Leaf stage	Leaf stage	Seed in dough stage	50% brown
Bromus japonicus	Full bloom	Seed in dough stage	100% brown	100% brown
Calomovilfa longifolia	Leaf stage	Leaf stage	Seed ripe	Seed disseminating
Carex filifolia	Past flower	Drying	75% brown	75% brown
Festuca idahoensis	Full bloom	Seed ripe, dissem., 75% brown	Seed fully dissem. 90% brown	90% brown
Koeleria cristata	Full bloom	Seed ripe, dissem. 75% brown	80% brown	90% brown
Stipa comata	Full bloom	Seed disseminated, 50% brown	80% brown	90% brown
Stipa viridula	Beginning to head	Seed ripe-dissem., green	Seed fully dissem. 25% brown	50% brown
Artemisia frigida	Leaf stage	Leaf stage	Begin to bloom	Begin to bloom
Yucca glauca	Beginning to flower	Past flower, stalk green	Flower stalk brown	Flower stalk brown

Table 6. Soil moisture conditions under various stands and associated soils. Cow Creek exclosure, Fort Howes Ranger District. Soil moisture expressed in percent of oven dry weight of sample. Underscored values are less the soil moisture percent at 15 Atms., i.e., unavailable. 1966 15 atm values are not presented in Table 2 and are slightly higher for the Ocean Lake series than given for 196

Stand & Soil	Soil Depth (in.)	1965			1966					
		6/17	7/15	8/12	4/1	5/2	6/9	7/1	8/2	9/1
		%	%	%	%	%	%	%	%	%
	0-6	10.2	3.2	2.6	7.2	9.9	4.8		5.9	
Sand reed-	6-12	7.6	3.3	3.1	7.2	9.6	6.5		3.6	
grass	12-18	9.3	3.5	3.1	4.9	9.7	7.7		3.6	
Ocean Lake	18-24	9.1	5.0	4.0	3.2	6.8	7.6		3.8	
Sandy loam	24-30	9.5	5.7	4.3	3.7	3.8	8.2		4.7	
	30-36	10.0	6.9	4.6	4.9	7.7	6.2		5.0	
	36-42				7.3	7.3	8.0		7.1	
	0-6	13.3	5.6	5.7	12.9	14.1	8.1	8.7	10.6	9.7
Little Blue-	6-12	12.4	7.0	6.5	12.5	13.3	10.7	8.8	9.4	5.7
stem	12-18	13.6	10.3	9.4	16.2		13.4	12.5	11.0	14.9
Remmit	18-24	14.7	11.5	8.3	15.5		15.5	14.5	10.8	15.4
Sandy loam	24-30	15.6	12.0	7.8	12.2	14.7	15.0	11.5	9.8	
	30-36	14.6		8.9	10.2	13.6	11.3	11.1	9.5	
	36-42				7.5	9.2	9.9	8.4	8.5	
	0-6	13.5	4.8	4.0	15.4	18.9	6.8	5.2	9.5	2.9
Idaho Fescue	6-12	17.3	6.9	6.2	19.5	22.8	10.4	10.2	11.6	3.8
Vona	12-18	21.9	12.4	10.0	14.9	28.6	20.7	15.4	11.9	6.5
A-B/sandy	18-24	19.9	17.7	11.8	17.3	16.2	20.3	20.7	17.8	6.3
loam	24-30				17.5	18.8	18.6	19.2	18.3	11.4
C/silty clay	30-36				18.0	19.4	18.9	20.1	18.6	12.2
	0-6	13.6	5.0	5.0	13.3	17.2	6.7	5.9	8.9	11.6
Needle and	6-12	9.3	5.5	5.3	15.0	18.3	11.1	7.5	7.0	10.2
Thread	12-18	9.5	5.5	4.4	8.8	14.8	15.0	12.7	11.7	9.5
Remmit	18-24	8.9	5.0	4.3	12.2	13.9	16.0	13.9	13.4	11.9
Sandy loam	24-30	11.2	7.5	7.1	14.5	16.7	15.5	14.8	14.7	10.1
	30-36				10.4	12.2	10.4	9.5	13.2	9.9
	36-42				10.3	10.2	9.2	10.1	10.3	10.1
Green Needle-	0-6	17.9	9.7	12.4	21.2	23.8	12.1	9.5	13.1	11.2
grass	6-12	19.1	12.3	14.6	21.8	23.7	15.1	11.9	10.6	12.0
Thurlow-	12-18	18.5	13.1	11.4	21.7	24.1	19.2	13.9	11.8	10.2
Promise	18-24	16.1	11.0	9.1	21.8	23.9	20.4	15.6	12.3	8.2
Clay loam	24-30				12.4	14.3	15.9	14.5	11.2	11.5
Bluebunch	0-6	22.5	12.3	13.7	27.1	29.7	17.6	17.1	16.7	21.4
Wheatgrass	6-12	20.7	16.1	16.6	25.9	30.6	21.0	17.5	15.4	16.0
Midway	12-18	20.8	16.0	15.7	18.7	25.9	21.6	17.0	15.3	14.7
Clayey	18-24	17.2	15.4	15.2	16.7	17.3	17.1	16.5	16.0	14.9
	24-30				17.9	17.4	17.7	17.2	16.9	14.5
	30-36				17.1	16.0	17.2	17.4	16.5	12.2

While it appears that there is more soil moisture in the Idaho fescue site than in the needle and thread site it had less moisture than the 15 atmosphere rating for each. They both have about the same net response to available moisture. Needle and thread soil based on the 1966 data, was not as dry in August as the Idaho fescue. They both dried faster than the two previous soils discussed but slower than the bluebunch wheatgrass.

Bluebunch wheatgrass soils had less available moisture in the subsoil early in the sampling period in comparison with all other sites. Green needlegrass site was nearly equal in this respect in 1966. It also showed some additions of moisture to the first foot in 1965.

In general, soil texture contributed material to the unavailability of soil moisture and the seasonal growth or period of plant activity and topography had complimentary effects on the pattern of available soil moisture.

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AREA-WEIGHT RELATIONSHIPS FOR COMMON MONTANA SHRUBS

T. Weaver*

INTRODUCTION

It has been shown that one can predict biomasses of trees from easily measured dimensions such as diameter or diameter and height. Tables for estimation of the volumes of merchantable wood in tree trunks have been used by foresters for well over 100 years (6, 2). Recently there has been increasing interest in the estimation of biomasses of whole trees and of various tree components from allometric relationships (4, 3, 7).

Regression lines of tree weight against diameter or diameter-squared-height for a variety of trees are rather similar. For merchantable volume tables representing one species often overlap those representing other species heavily (6). Regressions of other components against tree size also show the similarity of weight allocation (3, 7, and Weaver and Forcella, in prep).

This paper reports a test of the hypothesis that weights of shrubs can be predicted with equal ease: that shrub weights can be predicted from simple measures of their sizes and that size-weight relationships are similar for a variety of shrubs.

METHODS

Representatives of twelve shrub species were harvested in Gallatin County, Montana; separated into leaves, small twigs (0-0.5 cm), larger twigs (0.5-1 cm), large wood, and roots; and dried to constant weight on 60°C. The species studied were *Artemisia arbuscula*, *A. tridentata* (r), *Cercocarpus ledifolius* (r), *Cornus stolonifera* (r), *Physocarpus malvaceus*, *Potentilla fruticosa*, *Prunus virginiana*, *Purshia tridentata*, *Rhus trilobata* (r), *Sarcobatus vermiculatus* (r), *Sheperdia canadensis*, and *Vaccinium membranaceum* (r) (Booth and Wright 1959). Roots were collected only from those followed by (r).

The logarithms of dry weights of various components were regressed against the logarithms of the area, volume or basal area of the shrubs sampled. Area was calculated as (maximum diameter/2)x(minimum diameter/2)x pi, which reduces to pi x radius-squared if the shrub appears circular from above. The index of volume used was area x height. Basal areas were estimated from sections taken at ground level.

RESULTS AND DISCUSSION

The area-weight relationships of the shrubs studied are summarized in Table 1 with the regression equations on which the table is based and with measures of the reliability of those equations (r^2, E). Regressions of weights against shrub volume (r^2= 0.78, 0.73, 0.52, and 0.89 for total aboveground, twigs

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0-0.5 cm. leaves and roots (1+cm) respectively) and basal area (r^2= 0.85, 0.80, 0.58, and 0.84) were generally poorer than those of weight against area and are not, therefore, summarized here.

Table 1 suggests that:

1) Weights of aboveground parts of shrubs increase non-linearly with increasing area. They heavy weight per unit area of large shrubs is surely due to large supporting branches not found in smaller shrubs.

2) The proportion of 0-0.5 cm wood decreases from about 0.5 in small shrubs to about 0.2 in large shrubs with large amounts of supporting structure.

3) The large root (1 + cm) biomass of a shrub is approximately equal to the small branch biomass.

4) The leaf biomass of a shrub equals 0.20-0.25 times the small branch biomass. The constancy of this relationship might be expected since a function of small branches is the support of leaves (5). Though there is a general relationship between the area of a shrub and the weight of its leaves the relationship between the area of a shrub and the area of its leaves is not general. This is because different shrubs have different surface areas per gram of leaf: values we recorded were *Cercocarpus ledifolius* 17 cm^2/gm, *Sheperdia canadensis* 44, *Purshia tridentata* 62, *Sarcobatus vermiculatus* 43, *Artemisia tridentata* 47, *A. arbuscula* 62, *Physocarpus malvaceus* 74, *Rhus trilobata* 100, *Prunus virginiana* 139, *Cornus stolonifera* 159, and *Vaccinium membranaceum* 182.

5) The r^2's of 0.88-0.63 suggest that the equations discussed are fairly reliable and that the area-weight relationships are similar for a variety of shrubs occupying sites ranging from moist to very dry.

6) E values are another measure of confidence; a value of 1.4 tells us, for example, that actual shrub weights lie between the tabled value/1.4 and the tabled value x 1.4 (ref. 7).

Size-weight relationships and especially area-weight relationships should be useful for estimating the biomasses of shrubs in a variety of ecosystems.

1) If one is sampling on the ground he can tally shrubs in a plot by size class and multiply their numbers by weights taken from Table 1 or calculated from the regression equations provided.

2) One can probably make the required measurements with even greater speed from aerial photographs with scales (1:2500-1:500) suitable for determinations of shrub density and shrub diameters.

A word of cauton of those wishing to estimate browse biomasses: the shrubs on which this study was based were browsed lightly or not at all. If one estimates biomasses in an area where diameters are reduced 'artifically' by browsing actual

TABLE 1

Area-weight relationships for common Montana shrubs.[1,2]

Diameter[3] (cm)	Area[4] (dm^2)	Weight (kg)			
		Total above ground[5]	Wood 0-0.5 cm[6]	Leaf[7]	Root 1 cm +[8]
0	0	0.00	0.00	0.00	0.00
20	3	0.02	0.01	0.00	0.01
40	13	0.11	0.04	0.01	0.03
60	28	0.25	0.08	0.02	0.07
80	50	0.51	0.16	0.04	0.13
100	79	0.91	0.25	0.06	0.22
120	113	1.41	0.38	0.08	0.33
140	154	2.14	0.53	0.11	0.47
160	202	3.02	0.71	0.15	0.65
180	254	3.89	0.91	0.18	0.83
200	314	5.25	1.15	0.22	1.07
220	380	6.62	1.41	0.27	1.32
240	453	8.33	1.74	0.32	1.62
260	531	10.00	2.04	0.38	1.95
280	584	11.50	2.24	0.42	2.14
300	707	14.50	2.82	0.50	2.70

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[1] Unpublished data of T. Weaver, Biology Department, Montana State University, Bozeman.

[2] Five or more specimens of each of the following shrub species were collected for analysis: *Artemisia arbuscula*, *A. tridentata*, *Cercocarpus ledifolius*, *Cornus stolonifera*, *Physocarpus malvaceus*, *Potentilla fruticosa*, *Prunus virginiana*, *Purshia tridentata*, *Rhus trilobata*, *Sarcobatus vermiculatus*, *Sheperdia canadensis*, and *Vaccinium membranaceum*.

[3] The diameters given are for circular shrubs whose areas can be calculated as pi x r^2.

[4] Areas were calculated as pi x(maximum diameter/2) x(minimum diameter/2) because most shrubs were not circular.

[5] Log total aboveground biomass = -1.95 + 1.26 log area $r^2 = 0.85$ E = 1.40

[6] Log 0.0-0.5 cm wood biomass = -1.84 + 1.09 log area $r^2 = 0.77$ E = 1.45

[7] Log leaf biomass = -2.10 + 0.99 log area $r^2 = 0.63$ E = 1.45

[8] Log 1.0 cm + root biomass = -2.10 + 1.14 log area $r^2 = 0.88$ E = 1.38

browse will be overestimated while both above ground biomass and potential browse will be underestimated.

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